RESOURCES OF NON-SALMONID PELAGIC FISHES OF THE GULF OF ALASKA AND EASTERN BERING SEA

PART 1

INTRODUCTION

GENERAL FISH RESOURCES AND FISHERIES

REVIEW OF LITERATURE ON NON-SALMONID PELAGIC FISH RESOURCES

BY:

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-- INTRODUCTION

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FOREWORD

This review summarizes both published literature and data obtained from ex-
ploratory fishing and research on selected **non-salmonid** pelagic fishes of
the eastern Bering Sea and the Gulf of Alaska. It is subdivided into 5 sec-
tions which are presented in three parts:

Part 1

    Section I : Introduction
    Section II : General Fish Resources and Fisheries
    Section III : Review of Literature on **Non-salmonid**
                   Pelagic Fish Resources

Part 2

    Section IV : Historical Data Record of **Non-salmonid**
                   Pelagic Fishes

Part 3

Data Appendices

Section I presents background information for the project, scope of coverage,
list of fishes selected for review, and descriptions of the areas covered.
Section II discusses briefly the general fish resources and fisheries of the
eastern Bering Sea and Gulf of Alaska. Section 111 contains synopses of know-
ledge from the published literature about the distribution, life history,
biology, physiology, and fisheries of the 24 species or groups of fishes selec-
ted for coverage.

Section IV is a compilation of data records on the relative abundance and dis-
tribution of the species under study obtained from published and unpublished
records of research by a number of academic and governmental sources. The
section **lists** the data sources, the types of sampling gear used by various
agencies, and a brief review of survey targets and methods of the agencies.
Actual data are summarized in Sections **IV.A.** and **IV.B.** Section **IV.A.** consists
of 52 computer-produced charts showing the distribution of combined effort and
catches by gear and by season in the eastern Bering Sea and the Gulf of Alaska.
Section **IV.B.** contains 288 charts and graphs showing the relative abundance of
each species or group of species **by gear** type and by season in each of the
geographic areas considered.

The Data Appendices consist of (A) tables of coding format and coding used in
the compilation and analysis of published and unpublished historical survey
record data, (B) a computer listing of the station and haul data included in
the historical data record, and (C) 190 computer-generated plots (with land
masses **overlayed)** of the seasonal catch-per-unit-effort by gear of **non-salmon-**
id pelagic fish species.

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In addition to the literature reviews in Section III, a bibliography by Janet M. Wall and Paul T. Macy entitled, "An annotated bibliography on non-salmonid pelagic fishes of the Gulf of Alaska and eastern Bering"Sea,[1]' was issued for the Outer Continental Shelf Environmental Assessment Program (OCSEAP) in September 1976 as a processed report of the Northwest and Alaska Fisheries Center, Seattle, Washington. Also, a 9-track data tape, NWF 023.PR760801, was submitted, along with a "Description of the Data Record Report", to OCSEAP in October 1976.

Our intention is to provide scientists and administrators with a review of knowledge about non-salmonid pelagic fish species in the eastern Bering Sea and Gulf of Alaska by bringing information and data together in a form not previously available.

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RESOURCES OF NON-SALMONID PELAGIC FISHES OF
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I.   INTRODUCTION

The increasing need for new petroleum reserves in the United States has
resulted in accelerated gas and oil exploration and development in offshore
areas of Alaska. At the same time, the United States Government has been
concerned with the environmental risks involved with the development of
offshore petroleum reserves such as those proposed in the eastern Bering
Sea and Gulf of Alaska (Figs. 1.1, 1.2).

The Bureau of Land Management (BLM), Department of the Interior, has the
responsibility of managing offshore leasing of the outer continental shelf
(OCS). BLM is required by law to provide Environmental Impact Statements,
environmental studies and data acquisitions, literature surveys, and other
information needed for sound, integrated management of the OCS environment.
In 1974, the National Oceanographic and Atmospheric Administration (NOAA),
at the request of BLM, began a program to provide data on the biological
and physical environment for   BLM.

NOAA's program in Alaska is coordinated by its Environmental Research Labora-
tory (ERL) through ERL's Outer Continental Shelf Environmental Assessment
Program (OCSEAP). OCSEAP has arranged for the National Marine Fisheries
Service (NMFS) and other NOAA agencies, federal agencies outside of NOAA,
the State of Alaska, and various universities to conduct environmental
studies.

The Northwest and Alaska Fisheries Center (NWAFC) received contracts from
OCSEAP in September 1975 for a project to review literature and data for
resources of non-salmonid pelagic fishes of the eastern Bering Sea and
Gulf of Alaska. This report and a supplementary annotated bibliography
summarize the status of knowledge on resources of the subject species and
fulfill NWAFC's specific contract obligations.

OBJECTIVES OF STUDIES

The basic objectives of the studies are to provide: (1) an inventory and
review of the literature and unpublished data on the non-salmonid pelagic
fishes of the eastern Bering Sea and Gulf of Alaska, and (2) a description
of the temporal and spatial distributions of the subject species based
on analysis of available historical and research data. The report includes
synoptic information from the literature on the life history, distribution
and abundance, and (where practicable) population dynamics and fisheries
for the subject species. It also includes records of the data on distribu-
tion, abundance, and size composition obtained from the examination of
unpublished data files.

SCOPE OF COVERAGE

Pelagic fishes are found in greatest concentrations near the surface and
the immediately underlying waters. They feed and migrate over long distances.
Some are schooling species and are the object of intensive fisheries, while
others provide valuable forage for fish, birds, and mammals.
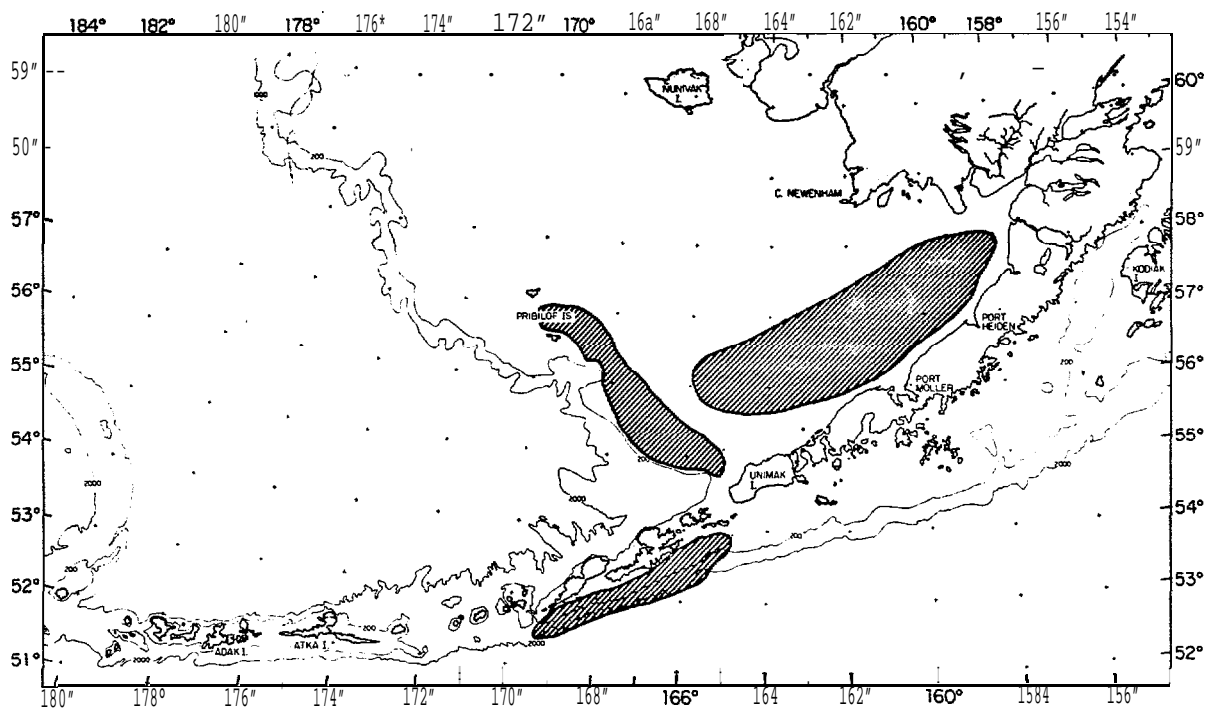
Figure 1.1.--Proposed oil lease areas, eastern Bering Sea and western
Gulf of Alaska.
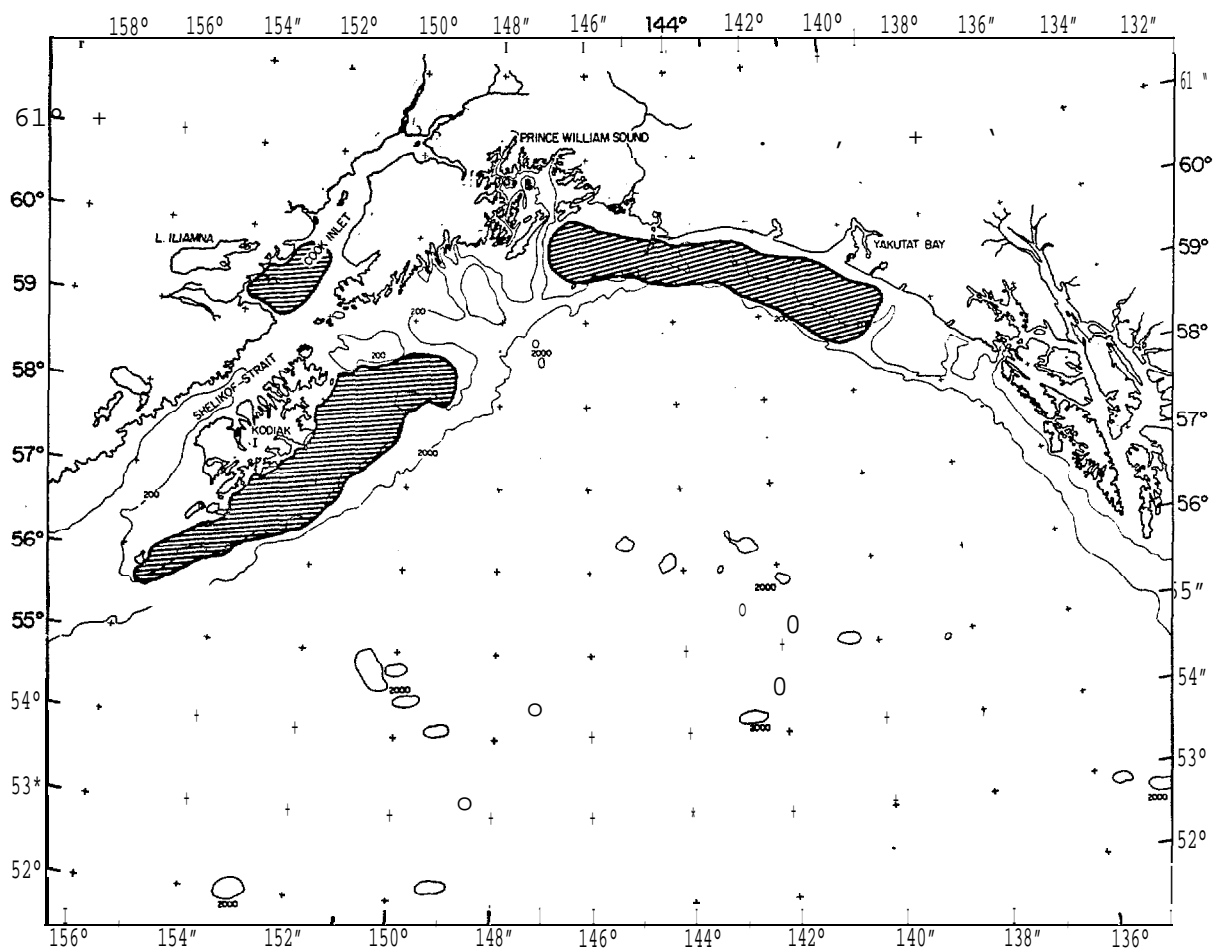
Figure I. 2.--Proposed oil lease areas, Gulf of Alaska.

For the purposes of this study, **non-salmonid** pelagic fishes were conceived to be those which spend the majority of their lives, and especially their post juvenile stages, in the near-surface and midwater layers and are" **primarily** sampled with , and exploited by, off-bottom gear. This latter qualification has had the effect of placing **semipelagic** gadoid (e.g. **pollock)** and **scorpaenid** species in the **demersal** realm , and thus outside the scope of this study.

Individual species were selected for study on the basis of their prominence in the catches of both United States and foreign commercial fishing fleets, their relative abundance in research vessel catches indicating potentially latent resources, and/or their prominence in the provision and maintenance of ecological balance as major predators, competitors, and forage fish. The final list of species considered in the study (Table 1.1) includes 15 families and 34 species for which narrative literature reviews have been prepared or for which sampling data are available.

The distribution and abundance of each species throughout the study areas has been found to be quite variable. Further, following examination of the available information, it became apparent that the optimum treatment of certain poorly known groups (e.g., **Myctophids, Bathylagids)** would be at the family level, while for others (e.g., **Osmerids)** additional treatment on an interspecific basis might alleviate some of the inadequacies and controversies observed in the data bases and the literature.

In the geographic areas of concern, **specific** sampling for the subject species has been very limited , and the obvious deficiencies of non-specific sampling and incidental catch records effectively precluded any in-depth analysis because the reporting of incidentally caught non-target species has been quite often incomplete and subject to quantitative and qualitative errors. In view of the above, a secondary objective in this study is to identify and evaluate gaps in our knowledge concerning the subject species.

Finally the scope of this study has been further delimited so as to exclude discussion on taxonomy, **speciation,** industrial and commercial utilization, and potential effects of contaminants on the subject species.

DATA SOURCES

All sources of published and unpublished information available to us were reviewed. For the literature review and annotated bibliography, we examined major abstract sources and indices such as Biological Abstracts, Current Fisheries Abstracts and Sport Fisheries Abstracts. In addition, we requested computer printouts of specialized subject bibliographies from three files in **NOAA's** Oceanic and Atmospheric Scientific Information System **(OASIS)--Bio**logical Abstracts (1964-1975), Biological Information Retrieval System (1972-75), and Oceanic Abstracts (1964-present). Special fishery publications. indexes and bibliographies of the United States **(Aldous** et al. 1955; George Washington University 1969; **Quast** and Hall 1972); Canada (Bishop et al. 1957; Carter 1968, 1973; Day and Forrester 1971) ; and the U.S.S.R. **(Romanov** 1959; **Potapova** 1965) also were searched. The more comprehensive scientific papers on fishery investigations in the subject areas yielded additional references. Translations of foreign literature were obtained from various sources. In all, more than 1,200 references have been examined and about 450 were retained for use either in the annotated bibliography or for preparation of the narrative review. Library resources for literature were principally the **NWAFC** library and the University of Washington library system.

Table 1.1.--Families and species of **non-salmonid** pelagic fishes selected
    for review.

Scientific Name   Common Name

Lamnidae   Mackerel sharks
    Cetorhinus maximus   Basking shark
    Lamna ditropis   Salmon shark

Carcharhinidae   Requiem sharks
    Prionace glauca   Blue shark
    Galeorhinus zyopterus   Soupfin shark

Squalidae   Dogfishes
    Squalus acanthias   Spiny dogfish

Clupeidae   Herrings
    Clupea harengus pallasi   Pacific herring
    Alosa sapidissima   American shad

Osmeridae   Smelts
    Hypomesus olidus   Pond smelt
    Hypomesus pretiosus   Surf smelt
    Mallotus villosus   **Capelin**
    Osmerus mordax   Rainbow smelt
    Spirinchus thaleichthys   Longfin smelt
    Thaleichthys pacificus   **Eulachon**

Bathylagidae   Deepsea smelts
    Bathylagus milleri   Stout **blacksmelt**
    Bathylagus pacificus   Slender **blacksmelt**
    Bathylagus schmidti   California **smoothtongue**
    Bathylagus stilbius   California **smoothtongue**

Myctophidae   Lanternfishes
    Ceratoscopelus townsendi   Dogtooth **lampfish**
    Diaphus theta   California **headlightfish**
    Hierops (Protomyctophum) crockeri   **Flashlightfish**
    Hierops (Protomyctophum) thompsoni   Bigeye lanternfish
    Lampanyctus ritteri   Broadfin **lampfish**
    Stenobrachius leucopsarus   Northern **lampfish**
    Tarletonbeania crenularis   **Blue lanternfish**

Scomberesocidae   **Sauries**
    Cololabis saira   Pacific saury

Carangidae   **Jacks**
    Trachurus symmetricus   Jack mackerel

Bramidae   Pomfrets
    Brama japonica   Pacific pomfret

Trichodontidae   Sandfishes
    Trichodon trichodon   Pacific sandfish

Table I.I--Families and species of **non-salmonid** pelagic fishes selected for
'review (cent'd).

<u>Scientific Name</u>   <u>Common Name</u>

Zaproridae   Prowfishes
      <u>Zaprora</u> **silenus**   Prowfish

Ammodytidae   Sand lances
      <u>Ammodytes hexapterus</u>   Pacific sand lance

Scombridae   Mackerels and tunas
      Scomber <u>japonicus</u>   Chub mackerel
      <u>Thunnus</u> <u>alalunga</u>   Albacore
      Thunnus thynnus   Bluefin tuna

Hexagrammidae   Greenings
      Pleurogrammus <u>monopterygius</u>   Atka mackerel

Sources of historical data records from catches and exploratory fishing
by various agencies are discussed and reviewed in Section IV, Historical
Data Record of Non-salmonid Pelagic Fishes, in this report.

DESCRIPTIONS OF AREAS

Eastern Bering Sea

The Bering Sea, considered an extension of the North Pacific Ocean, covers
an area of more than 2,300,000 km^2. It is connected with the Arctic Ocean
on the north by the shallow Bering Strait and with the open Pacific Ocean
on the south by straits of varying depth and width through the Aleutian
Island chain. The area considered for this study is about one-third the
total area and includes the portion extending from 52° to 600N lat. and
from 1800 eastward to the Alaskan coast (Fig. 1..3).
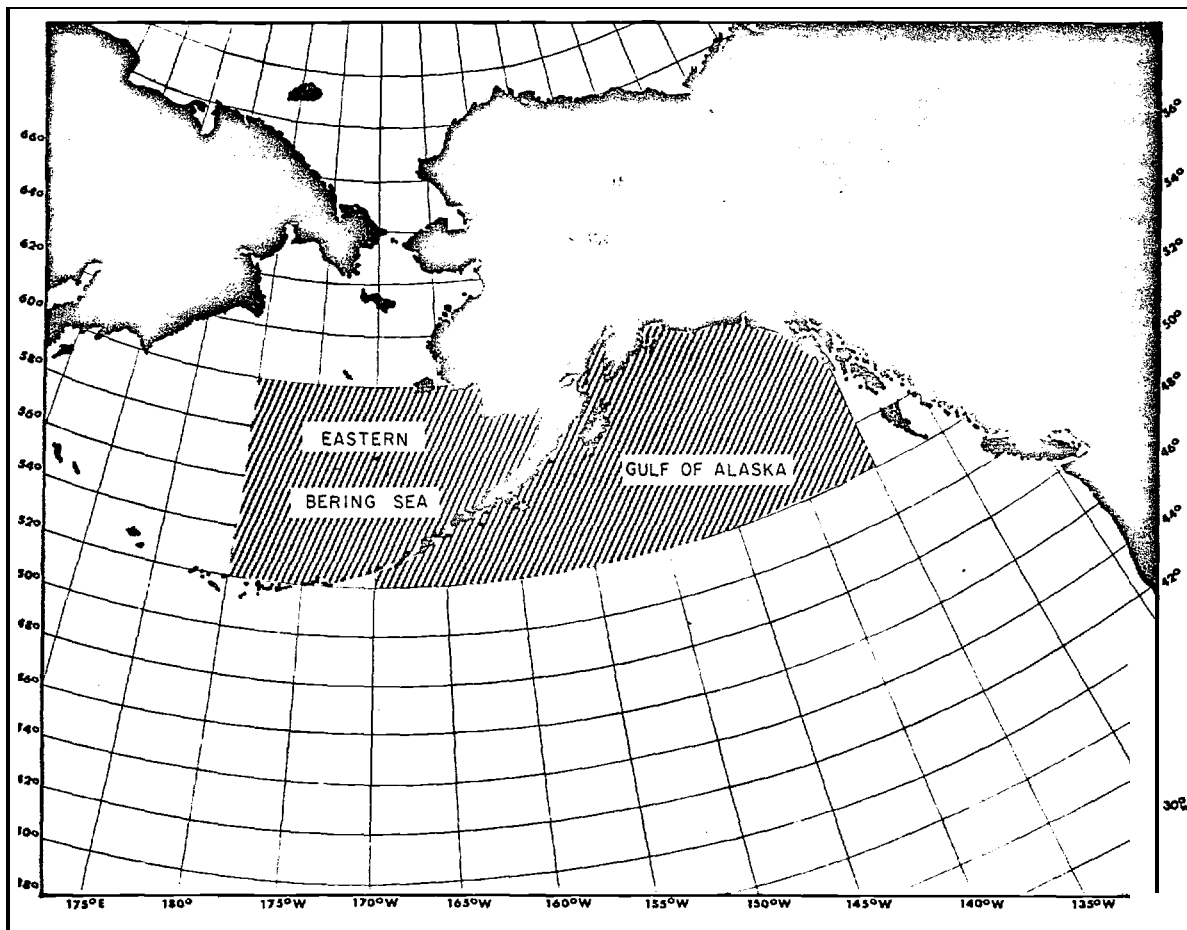
Figure 1.3.--Eastern Bering Sea and Gulf of Alaska study areas.

Two of the depth zones are somewhat equal in size and comprise the bulk
of the sea—the neritic (O to 200 meters; nearly 37%), mostly in the north-
eastern part, and the abyssal in the southern and central part (exceeding
2,000 m; about 49%) (Moiseev 1963, Favorite 1966). The continental shelf
of the Bering Sea occupies about 44 percent of the total area, being widest
(400 miles or 670 km) in the eastern and northern part. Depths on the con-
tinental shelf average about 60 meters and the bottom is sandy, changing
to silt near the continental slope.

The Bering Sea has three distinct water masses (Favorite 1966). Water over
the shallow continental shelf is cooled in winter from surface to bottom
by convection currents under the ice, diluted in spring by runoff from
large rivers, and warmed in summer at the surface. The resulting temperatures
range from -1.6°C to 10"C, and surface salinities are 22 to 32.8 °/oo.
Waters in the surface layers (0-150 m) over the deep basins are modified
seasonally and have temperatures of 1 to 9°C and high surface salinities
of 32.9 to 33.2 °/oo. Water deeper than 200 meters in the central basin
originates in the Pacific Ocean in depths of more than 600 m, producing
cold, oxygen-depleted water within 200 m of the surface.

Ice begins forming in the northern Bering Sea in October, is usually at
maximum in February when its southern limit is from Bristol Bay to the
vicinity of St. George Island , and starts breaking and moving north in
April. Ice does not form along the Aleutian Islands and the western end
of the Alaska Peninsula.

The surface currents in the Bering Sea flow in a generally counterclock-
wise direction, eastward on the north side of the Aleutians and northward
in the eastern part of the Sea. Cyclonic and anti-cyclonic eddies are pro-
duced in the eastern part of the Sea, and part of the northward flow into
Bering Strait splits off to flow southwestward along Kamchatka.

The waters of the continental shelf of the Bering Sea are the most productive
in the world. Demersal species such as Pacific ocean perch, Pacific cod,
sablefish, Alaska pollock, and halibut and other flatfishes are caught
in huge quantities, but salmon, herring, and Atka mackerel are the only
pelagic fishes that have been commercially important. Other pelagic fishes
are valuable as food for other fishes, for mammals, and for birds.

Biological productivity and the distribution and movements of fishes are
influenced by seasonal oceanographic conditions and bottom relief features.
The migration, movement, spawning, feeding, and other behavior of fish
is motivated and modified by seasonal temperature and productivity changes
in various areas. Currents from the Pacific Ocean bring warmer water into
the Bering Sea through channels in the Aleutian Islands and modify colder
waters. Gyral currents result in development of fish concentrations. Upwelling
of deep waters on the Bering Sea slope carries nutrients to the surface
to bring about high productivity. The production of phytoplankton peaks
in July-September in the eastern part of the Sea when maximum density reaches
about 10 g/m3 (Moiseev 1964). Moiseev noted that the zooplankton concentra-
tion in some years in the eastern shallows may be as high as 0.5 g/m^3 and
the amount of food benthos on shelf areas of the southeastern region totals
7,000,000 metric tons.

Gulf of Alaska

The Gulf of Alaska as considered in this study is that area from off the Queen Charlotte Islands at about 52oN lat. and 135W long. westward to the Aleutian Islands and northward to the Alaska coastline (Fig. 1.3).

The area covers 1,327,000 km^2, including Cook Inlet and Shelikof Strait. The continental shelf occupies 300,000 km^2 (23% of the total) in which the water depths are less than 150 m, and the shelf is widest (more than 200 miles or 330 km) in the vicinity of Kodiak Island (Moiseev 1964). In many places gullies or canyons cut through the shelf, and Moiseev states that warm deep waters of Pacific origin rise in these depressions, especially in winter, to create favorable conditions for development of concentrations of fish. The bottom types vary from muddy and sandy to rocky; in some places rocks and boulders make trawling difficult or impossible.

Circulation in the Gulf of Alaska is cyclonic. Waters of the North Pacific Ocean flow eastward as the Subarctic Current System between approximately 400 and 50°N lat. and split at about 150w long. into the southbound cold California Current System and the northbound, relatively warm Alaska Current System (Plakhotnik 1964; Favorite, Dodimead, and Nasu 1976). The Alaska Current System flows in a counterclockwise direction in the Gulf westward along the Alaska Peninsula as the Alaskan Stream.

The water temperatures vary, according to Moiseev (1964), from 10-12°C in the surface layer at a depth of 0-10 m, and from 3-6°C at a depth of 200-200 m or more, i.e. , on the upper part of the continental slope.

Biological productivity is relatively high in the Gulf because rich waters are brought to the surface by upwelling along the submerged valleys and canyons. The average benthos biomass at the shelf is 130 g/m^2, the biomass of food benthos is 80 g/m^2, and the total amount of food benthos on accessible shelf regions is 33,000,000 metric tons (Moiseev 1964; Shevtsov 1964).

II. GENERAL FISH RESOURCES AND FISHERIES

According to Wilimovsky (1974), the fish fauna of the Bering Sea totals
approximately 300 species from 40 families of which 8 families comprise
more than 70 percent of the total species (Table 11.1). Approximately 235
species are found in the eastern Bering Sea. A recent list by Fedorov (1973b)
totals 393 species for the Bering Sea. however, including marine, diadromous,
semi-diadromous, and freshwater fishes of the Sea and the rivers flowing
into it.

Table 11.1.—Proportion of eight predominant families to total species
composition of Bering Sea fish fauna (about 300 species) and Gulf
of Alaska fauna (about 308 species).[1/]

Family	Percentage of total fish species	
	Bering Sea	Gulf of Alaska
Cottidae	22	17
Cyclopteridae[2/]	15	11
Stichaeidae	8	5
Pleuronectidae	8	5
Zoarcidae	6	4
Agonidae	5	4
Scorpaenidae	5.	11
Salmonidae	4	3
Total of eight dominant families	73	60

1/ Bering Sea data from Wilimovsky (1974); Gulf of
   Alaska data from Quast and Hall (1972).
2/ Listed as Liparidae by Wilimovsky.

Wilimovsky states that in the Bering Sea the cottoid and stichaeid groups
dominate the shore fishes, and the benthic fishes form two broad groups:
one composed of wide-ranging species such as pleuronectids and. lycodids
and the other of very deep-water benthic forms represented by several families
of one or two species each. In vertical distribution, the pelagic and bathy-
pelagic fishes comprise about 40 species, the inshore fishes about 80 species,
the benthic fishes 150 species, and the deep benthic fishes about 35 species.

The greatest quantities of bottomfishes by weight in trawl catches in the
eastern Bering Sea come from four families: the sculpins (family Cottidae),
cods (family Gadidae), flatfishes (family Pleuronectidae), and eelpouts
(family Zoarcidae). The ten most abundant demersal species based on average
catch rates by area and depth zones and computed standing stock sizes are
shown in Table 11.2.

Table 11.2.—Ten most abundant demersal fishes of the Bering Sea and
Gulf of Alaska (adapted from **Alverson** 1968).

Area	
Bering Sea	Gulf of Alaska
Yellowfin sole	Arrowtooth flounder
Walleye **pollock**	Pacific ocean perch
Rock sole	**Flathead** sole
Flathead sole	Walleye **pollock**
Pacific cod	Rock sole
Pacific ocean perch	Pacific cod
Arrowtooth flounder	Dover sole
Starry flounder	Sablefish
Pacific halibut	Pacific halibut
Sablefish	Starry flounder

The pelagic fishes are relatively small-sized and diverse, and **Wilimovsky**
notes that, although biological data are lacking, many of the pelagic species
apparently carry out extensive seasonal movements both horizontally and
vertically. In the uppermost layers fishes such as Osmerus. Mallotus, and
Oncorhynchus of the **salmonid** group predominate. In deeper waters are found
scorpaenids, **gadids,** and macrourids. **Wilimovsky** writes, "With the exception
of the deep-sea **argentinids,** none of the pelagic forms appear to be endemic
to the Bering Sea, and the adult components of the pelagic fauna can only
be categorized broadly as North Pacific in character. As with most pelagic
forms, the species are wide-ranging and occur throughout the water masses
characterized as **'salmon water'** by the oceanographer."

Four species of Pacific salmon, Genus Oncorhynchus, are the most valuable
pelagic fishes. Of the **non-salmonid** pelagic fishes, the Pacific herring,
Clupea harengus pallasi, is both a commercial fish and an important forage
species for other fishes , mammals, and birds. Other important pelagic forage
species are the **capelin (**Mallotus villosus) and other smelts and the Pacific
sand lance (Ammodytes hexapterus).

The fish fauna of the Gulf of Alaska totals approximately the same (more
than 300 species) as that of the Bering Sea, but the predominant species
differ from those of the Bering Sea (Table 11.1). Approximately 64 families
are found in the **Gulf** of Alaska, 20 more than in the Bering Sea (Quast
and **Hall** 1972). The **cottids, cyclopterids,** and scorpaenids compose nearly
40 percent of the total fish species. The most important commercially valuable
bottomfishes include the sablefish (Anoplopoma fimbria), Pacific cod (Gadus
macrocephalus) , Pacific halibut (Hippoglossus hippoglossus stenolepis),
Pacific hake (Merluccius products), Pacific ocean perch (Sebastes alutus),
and the walleye **pollock** (Theragra chalcogramma). The ten most abundant
commercial species of **demersal** fishes are listed in Table **II.2.**

Commercially valuable pelagic fishes include the salmon species, Pacific
herring, and Atka mackerel (Pleurogrammus monopterygius). Surveys have
shown the possibilities of commercial fisheries for Pacific pomfret (Brama
japonica) and jack mackerel (Trachurus symmetricus) (Larkins 1964, Hitz
and French 1965).

The rich resources of the Bering Sea and the Gulf of Alaska make those
areas some of the most important fishing areas of the world. The first
fisheries to develop in the eastern Bering Sea and the western Gulf of
Alaska were for cod. Cod were first fished by United States fishermen in
the eastern Bering Sea in 1864 and in the Shumagin Islands area (western
Gulf of Alaska) in 1867 (Cobb 1927). Commercial halibut fisheries began
in the Bering Sea in 1930 (Dunlop et al. 1964).

The movement of foreign nations into fisheries in the eastern Bering Sea
started in the early 1930's and 1940's when Japan conducted exploratory
bottomfish operations and limited fishery operations (Alverson et al. 1964).
These operations were interrupted by World War II, but Japan began trawling
again in the area in 1954, followed by the entry of the U.S.S.R. in 1959.
Subsequently, the fishermen of the Republic of Korea (ROK) began fishing
in the late 1960's, and vessels of the Republic of China (Taiwan) arrived
in the early 1970's. The primary objectives of these nations were the demersal
fishes and shellfish. The target species in the late 1950's was yellowfin
sole; catches of Japanese and Russian vessels increased from approximately
30,000 tons in 1958 to 550,000 tons in 1961 (Alverson 1968). When yellowfin
sole catches dropped in 1962-64 because of decreased landings, efforts
shifted to walleye pollock which have composed the major part of foreign
catches since the mid-1960's. In 1971-74, the average annual landings of
walleye pollock were 1.7 million mt, and the average total catch of all
species of bottomfish in those years was approximately 2.1 million mt,
almost all catches being made by Japan and the U.S.S.R. As of 1964, Alverson
et al. (1964) wrote, "Removals from the eastern Bering Sea by Japan and
the U.S.S.R. since 1958 exceed the total combined landings of the United
States and Canadian Pacific Coast trawl fishery since its inception in
the late 1800's."

The Pacific herring is the only non-salmonid pelagic species to attain
substantial commercial importance in the eastern Bering Sea, although the
Russians have fished for Atka mackerel in the Aleutian Islands area. Russian
exploratory vessels discovered commercial quantities of herring north and
west of the Pribilof Islands in the late 1950's, and the first Soviet herring
fisheries were conducted in the winter of 1959-60 (Chitwood 1969). Japanese
herring fisheries began in the area in 1961 but never reached the magnitude
of the Soviet catches. The Russians took 10,000 tons the first year, fishing
reached a peak in 1962-64 when 150,000-175,000 metric tons were taken per
year, and catches have been limited to 30,000 mt in 1975 and 1976 under
a bilateral agreement with the United States (Pruter 1976). Catches by
Japan in the early years of the fishery were made with gillnets but did
not exceed 10,000 mt (Fisheries Agency of Japan 1974). Stem trawlers were
employed beginning in 1966-67; catches expanded to a peak of 44,000 mt
in 1968 and fell to 15,000 mt by 1970 (Pruter 1973).

The historic fisheries of the Gulf of Alaska were coastal fisheries by U.S. and Canadian fishermen seeking Pacific salmon, halibut, herring; and shrimps. In the 1960's, Russian and Japanese vessels entered the area and began trawling for bottomfish, primarily Pacific ocean perch. The peak catch of ocean perch was about 500,000 tons in 1965, after which catches began to decline (Alverson 1968). The foreign fleets subsequently turned their attention to other species such as Pacific cod, sablefish, Atka mackerel, flounders, grenadiers, and Alaska pollock (Pruter 1976). The Russians also moved south to fish ocean perch and hake off the coasts of Washington and Oregon.

Although the groundfish resources of the Gulf of Alaska are only about one-fifth as abundant as those of the eastern Bering Sea, their value is considerable. The foreign fleets annually catch about 230,000 mt valued at $48 million by U.S. standards (Reeves 1972). Landings by North American fishermen were about 30,000 mt per year, mostly from the Queen Charlotte Islands region, in the period 1956-69.

The fisheries on pelagic species in the Gulf of Alaska were limited until recent years to Pacific salmon, herring, and dogfish. Commercial salmon fishing began in the Kodiak Island area as early as 1867 when a saltery was established, and a cannery was built at Klawak in southeastern Alaska in 1878 (Cobb 1931). Peak salmon catches in the Gulf of Alaska were made in the middle 1920's to the mid-1940's, after which catches declined (Kasahara 1963) .

Commercial fisheries for Pacific herring in the Gulf of Alaska date from 1882 when an oil and fertilizer plant was established at Killisnoo in Upper Chatham Strait (Rounsefell 1930a).The fishery has been conducted principally in inshore channels and bays, and catches have fluctuated greatly from both natural causes and changing markets. '

The fishery for spiny dogfish was of little consequence until new demands for vitamin oils were created in the United States by the outbreak of World War II. It expanded rapidly, reached a peak in 1944, and decreased after 1949.

Atka mackerel had a long history of use by native fisheries, and limited commercial fishing developed for the species in the late 1800's and early 19001s. The first large catches of Atka mackerel in the Aleutians and western Gulf of Alaska (4,515 and 6,282 mt, respectively) were made in 1972 by Soviet vessels. More recently, Polish vessels fishing in the Kodiak Island area in 1975 caught as much as 46 mt per hour. The Soviets have intensive fisheries for this species in the Gulf of Alaska at present.

Further details of the biology, abundance, sampling, and fisheries for Pacific herring, spiny dogfish , and Atka mackerel are included in Sections III and IV, and Appendices A and B of this report.

111. REVIEW OF LITERATURE ON NON-SALMONID FISH RESOURCES

Only a portion of the total catches of fish in the eastern Bering Sea and
Gulf of Alaska are pelagic fishes, and the total potential yield of pelagic
fishes is unknown. Because so few species are commercially important, most
of the published literature is limited to the commercial species. Some
additional literature has been produced as the result of scientific observa-
tions made on non-commercial species during the course of research on commer-
cial species or during exploratory surveys to measure the fish resources
of particular areas.

To summarize the knowledge on non-salmonid pelagic fish resources of the
two geographic areas, we reviewed published and unpublished literature
to abstract information on fish distribution, abundance, life histories,
fisheries and population dynamics. When literature specific to the geo-
graphic areas by species was not available, we have referred to literature
on the species from other geographic areas. Thus most of the species reviews
are short synopses of all available information on the species as well
as being as specific as possible to the areas of interest.

In addition to the literature reviews in this section, a bibliography by
Janet M. Wall and Paul T. Macy entitled, "An annotated bibliography on
non-salmonid pelagic fishes of the Gulf of Alaska and eastern Bering Sea,"
was issued for OCSEAP in September 1976 as a processed report of the Northwest
and Alaska Fisheries Center.

As Alverson (1968) pointed out, the pelagic species have potential for
exploitation, "o..but all require further investigation before we can reliably
establish the size of the pelagic fish or invertebrate resources." The
review of the separate pelagic species and groups of fishes in this report
is a contribution toward the knowledge of pelagic resources and also should
point out types of research needed to fill gaps in our knowledge.

The literature reviews are presented in taxonomic order in this section.
The records of efforts and catches from historical data will be found in
Section IV.

BASKING SHARK (Cetorhinus maximus)
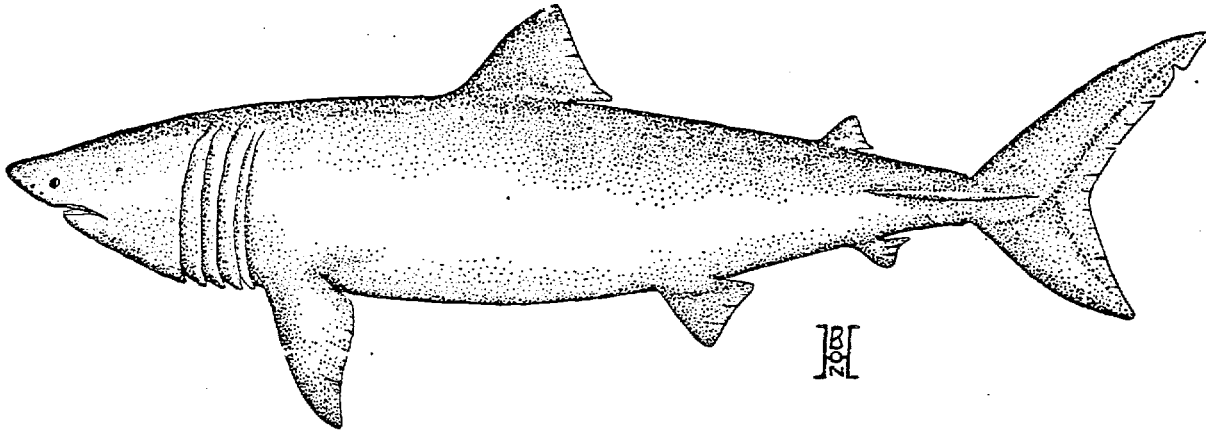
Figure III.1.1.--Basking shark, Cetorhinus maximus (from Hart 1973).

IDENTIFICATION

Cetorhinus maximus (Gunnerus) is the accepted scientific name for the basking shark, sometimes called the elephant or bone shark (Bailey et al. 1970). The Japanese common name is uba zame, and in Russian it is known as gigantskaya akula. Herald (1961) stated that, while there appears to be one worldwide species, some authorities believe several species may be involved.

The color of the basking shark is grayish brown to slaty gray to black above , and the underparts are the same color as the back or paler (Bigelow and Schroeder 1948).

DISTRIBUTION

The basking shark is found in temperate waters both in the Atlantic and Pacific Oceans. In the Pacific it is found from Baja California to the Gulf of Alaska; off Peru and Ecuador; off Japan and China; and off southern Australia and New Zealand (Hart 1973). It is evident in the northern part of its range in the Atlantic only in summer according to Bigelow and Schroeder (1948), but they note the fish may retire in fall and winter to deeper water.

Analyses by Larkins (1964) of species of fishes caught during studies
of the high seas distribution of salmon in the North Pacific Ocean, Bering
Sea, and Gulf of Alaska in 1955-61 showed the basking shark was rare,
only one being caught in the Aleutian Islands area. Analyses of historical
data of all agencies shows however, several instances of its capture in
our subject areas (see part IV, Historical data record of non-salmonid
pelagic fishes), and Clemens and Wilby (1935) said that it is common along
the British Columbia coast. Parin (1968) stated that the distribution
of the species is between the 6 and 20°C (43°-680 F) isotherms and in
ocean regions that are most productive. These factors would limit distribution
in the Gulf of Alaska and Bering Sea.

Because they are so rarely found in the North Pacific Ocean, most informa-
tion in this report is from studies in other parts of the world, and it
is presented with the assumption that life histories would be somewhat
similar in the Pacific Ocean.

LIFE HISTORY

Reproduction

Observations by Aasen (1966) indicated that basking sharks mature at ages
of 4-5 years and lengths of 5-6 m. Only the right ovary is developed,
and it contains at least 6,000,000 eggs, each about 0.5 mm in diameter.
Most of these degenerate. The length and age at maturity for females is
unknown.

Mating occurs in spring (Aasen 1966), and there is some evidence that
breeding occurs in May off the coast of Scotland, according to Matthews
(1950) who described apparent mating behavior. Evidence from scars shows
that only one clasper is introduced into the female at mating, and approx-
imately 15 liters of spermatophores may be deposited in the female in
a single mating.

Essentially nothing is known about embryonic growth, but Matthews notes
that if the gestation period was similar to that of the spiny dogfish,
Squalus acanthias, which is 22 months, breeding could obviously not recur
every year. Although evidence is incomplete, the species is believed to
be viviparous according to Matthews. The young are born in August, at
least in the Atlantic near the coast of Norway (Aasen 1966),

Bigelow and Schroeder (1948), summarizing data from a number of sources,
found evidence that the sharks are 5-6 ft (1.5-1.8 m) long at birth and
indications that males mature at lengths of 15-20 feet (4.6-6 m).

Growth and Nutrition

Growth

Matthews(1950) assembled data on various isolated catches and constructed
a growth curve that looks plausible with a starting length of about 6
feet (1.8m) at birth and a length approaching 30 feet (9 m) after six

years. The data are from the Atlantic and not the Pacific Ocean, however, and may or may not describe age and growth relationships for the shark of the Pacific Ocean. Aasen (1966) presented a length-weight curve and noted that a basking shark 1.5 m long would weigh 20 kg (Fig. 111.1.2).
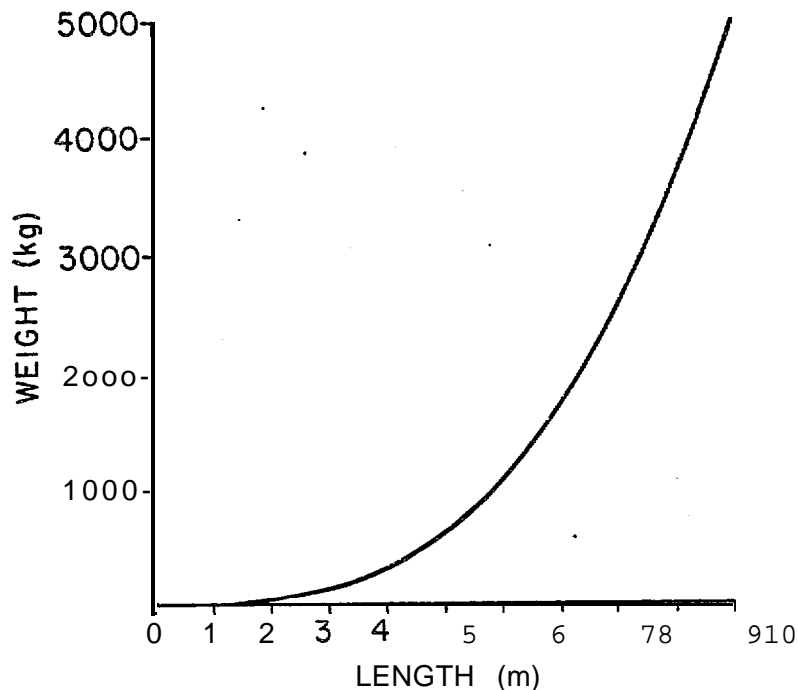
Figure 111.1.2.—Length/weight ratio for the basking shark (from Aasen 1966).

The basking shark is the world's second largest fish (Herald 1961). Matthews and Parker (1950) believe that its total length has been much exaggerated in the literature and the problem is probably caused by measurements being made around curves instead of in a straight line. Although lengths of 40 feet (12 m) have been reported, they state few, if any, exceed 30 feet (9 m). Bigelow and Schroeder (1948) found that two basking sharks caught at Monterey, California weighed 6.850 (3.107 kg) and 8.600 pounds (3,900 kg) . and measured 28 and 30 feet (8.5 and 9.2 m), respectively. Maximum age may be 20 years according to Aasen.

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Food and Feeding

The basking shark is an indiscriminate plankton feeder and subsists com-
pletely on small planktonic organisms sifted out of the water by means
of its gill rakers (Matthews and Parker 1950). The fish has five gill
arches each carrying 1,000-1,300 gill rakers up to 10 cm long. When feeding
near the surface, the basking shark cruises at about two knots with its
mouth open, and it is calculated to strain at least 2,215 cubic meters
of water, or over 4,000,000 lb, per hour. The stomach contents weigh about
half a ton, depending upon the size of the fish, and form a thick gelatinous
mass which is about 30% plankton and 70% mucous (Aasen 1966).

The food varies according to the season and the plankton available, but
it consists of plankton no larger than Calanus, according to Matthews
and Parker. Food includes fish eggs; copepods such as Calanus, Oithona,
and Pseudocalanus; and cirriped and decapod larvae.

Predators and competitors

No information available.

Parasites and Diseases

Practically every basking shark seen at sea carried one or more lampreys
(Petromyzon latipes) attached to it and all dead fish had marks caused
by the suckers (Matthews and Parker 1950). While the lampreys have been
seen attached, the denticles apparently prevented penetration of the skin
by the lamprey. Matthews and Parker also reported finding the large parasi-
tic copepod, Dinematura products, commonly attached to the skin; the copepod,
Nemesis lamna, was found on the gills and two species of the cestode,
Dinobothrium, were found in the spiral valve,

Physiology

Matthews and Parker (1950) describe various features of the anatomy and
biology of the species, but little is known.

Behavior

According to Aasen(1966), a study" of the feeding habits indicated that
energy loss may exceed energy intake in the winter. This suggests the
basking shark has a winter resting phase at a time and place unknown.
There have been reports, according to Aasen, that the shark sheds its
gill rakers in the winter and that they are regrown in the spring, This
unconfirmed observation would support the theory that there is a winter
resting phase. Basking sharks are found off California in the winter,
however, so there is some confusion as whether gill rakers are shed at
all, or only occasionally.

The basking shark is an inoffensive and sluggish fish that spends much of its time lying at the surface with the tip of the snout and caudal fins showing (Bigelow and Schroeder 1948). The basking behavior may be related to feeding or breeding. On some occasions, they gather in schools of 60 to 100 individuals.

Because pregnant females are rarely caught, in both the Atlantic and Pacific Oceans, they apparently cease basking when pregnant and go to either deeper waters or other areas.

Matthews and Parker (1950) reported that there is a spring inshore movement of these sharks to the coast of the British Isles and that nothing is known of where they go when they leave the coast. They also reported that there is a cyclic variation in the abundance of sharks over a period of . years in the Atlantic but no information is available on variations in abundance in the Pacific over a period of years.

POPULATION DYNAMICS

Nothing was found in the literature about the abundance, sex ratios, size and age composition, mortality, and other features of the basking shark in the Bering Sea and Gulf of Alaska.

Observations and records in European waters show that the abundance of the species has varied over the years (Bigelow and Schroeder 1948). For example, large numbers were reported off Wales in 1776 but have never been reported there since, and they were scarce along the Norwegian coast in the first half of the 18th century and around 1840 and were abundant about 1800 and 1880. Abundance has been so low in the western North Atlantic that only incidental captures have been made in the last 100 years, but Aasen (1966) lists fishery statistics in the eastern Atlantic for 1934-1965.

Matthews (1950) reported that females were more plentiful than males in the commercial catches in the Atlantic Ocean, although there was no reason to believe the fishery to be selective. At times there have been only one male to 30-40 females, and yet earlier investigators sometimes had only male sharks to examine. It is possible that there is a seasonal segregation by sex.

FISHING

Fisheries that developed to harvest the basking shark were small local fisheries to take the fish for their liver oil or for fish meal (Bigelow and Schroeder 1948). Fisheries have been conducted in past years in European waters, in the New England area, off central California and off the coasts of Peru and Ecuador (Herald 1961). Aasen (1966) presents a graph of commercial catch data in the Atlantic for 1936-65.

Although no specific fishery existed in British Columbia, the fish was taken incidentally in salmon gillnets and sunken dogfish nets during World War II, and the value of the oil defrayed the cost of repairing nets (Larkin and Ricker 1964). In recent years they were considered a nuisance and were shot or ran-reed to keep them out of nets.

Fishing for basking sharks is usually done from small boats with harpoons. In central California, a unique method uses a small spotting plane that locates a school, radios the fishing boat crew and circles the school until the fishermen arrive to harpoon the sharks (Herald 1961). About a hundred basking sharks were taken by this method in the Pismo Beach area of California in 1947.

Suggestions for Future Research

It is doubtful that commercial fisheries will be profitable for this species because of the small numbers available in the Gulf of Alaska and Bering Sea.

SALMON SHARK (Lamna ditropis)
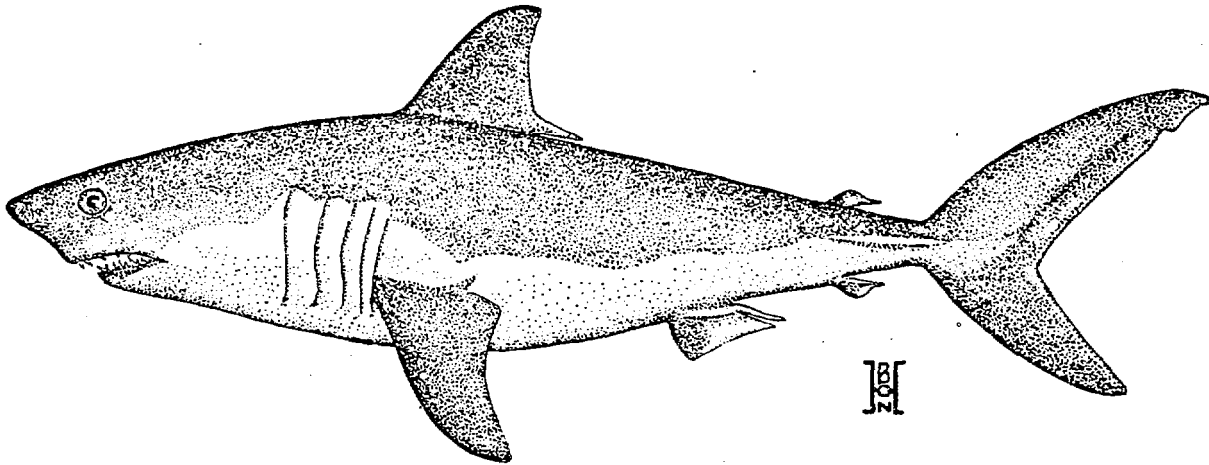
Figure III.2.1---Salmon shark, Lamna ditropis (from Hart 1973).

IDENTIFICATION

Lamna ditropis Hubbs and Follett (1947) is the currently accepted
scientific name for the shark commonly known as the salmon shark.
In the past, what is apparently the same species has had, or been
confused with, the following names: Isurus nasus Bonnaterre, Lamna
cornubica Gmelin and Lamna nasus Bonnaterre. While salmon shark is
the preferred common name (Bailey et al. 1970), the species has also
been called the porbeagle and mackerel shark. The Japanese common
names are nezumi-zame, mouka, and rakuda-zame, and the Russian common
name is Tikhookeanskaya sel'devaya akula (Okada and Kobayashi 1968).

There is no direct evidence of subspecies, but Herald (1961) referred
to the Atlantic porbeagle, Lamna nasus, as having a related American
Pacific Coast species, Lamna ditropis. He also mentioned a species
occurring in South America and Australia which' further studies might
show to be identical to the Pacific Lamna ditropis.

DISTRIBUTION

Wilimovsky (1954) described the distribution of L. ditropis as being
from Alaska to California and Japan. The species is pelagic, it inhabits
temperate and subarctic waters from San Diego and southern California
northward to Alaska and the Bering Sea to Japan, and it occurs throughout
the year in the Gulf of Alaska (Hart 1973). It goes to the Okhotsk
Sea on seasonal feeding migrations according to Fedorov (1973a), and
it is not found in the open ocean south of lat 35° N (Parin 1968).

While the above are the commonly known and accepted places of occurrence,
the writings of Herald (1961) and Nakaya (1971) suggest that different
populations might occur or that-the salmon shark may have a much broader
distribution than is known.

Sano (1959) reported that the abundance of salmon shark is very high
along the Aleutian islands, especially along the northern side, and
that they are more abundant in fishing areas than to the west close
to the Kamchatka Peninsula. Since salmon shark are also abundant along
the central Kurile Islands, he assumed there are two different popula-
tions, one in the Kuriles, the other in the Aleutians. Nothing was
found in the literature about specific distribution in the eastern
Bering Sea,but Neave and Hanavan (1960) mentioned that the salmon
shark has been taken in June at lat 55° N in the Bering Sea.

Distribution of salmon shark in the Gulf of Alaska in 1956-57 is shown
in Fig. 111.2.2 from Neave and Hanavan (1960) who state that it may
possibly be ". . . the only sizeable species of fish which can be
expected to occur in the surface waters of all parts of the region
under discussion at all seasons of the year."

Nothing is known about the distribution of juvenile and smaller sizes
of salmon shark.

Fedorov (1973a) states that the salmon shark is a neritic and epipelagic
species, and it occurs in waters up to 200 meters deep. Neave and
Hanavan (1960) found that the sharks were caught in gill nets fishing
in temperature ranges from 7.6° C to 17.2° C, and they pointed out
that these limits were insufficient to cover the full range of tolerance
for the species. According to Sano (1959), surface water temperatures
in the Aleutian Island areas ranged from 2.5 to 5° C in May, 4 to
8° C in June, 6 to 10° C in July and 7.5 to 10° C in August in places
where salmon sharks were caught. He stated the distribution related
to the area where the westward flowing Alaska current came in contact
with a cold water mass.
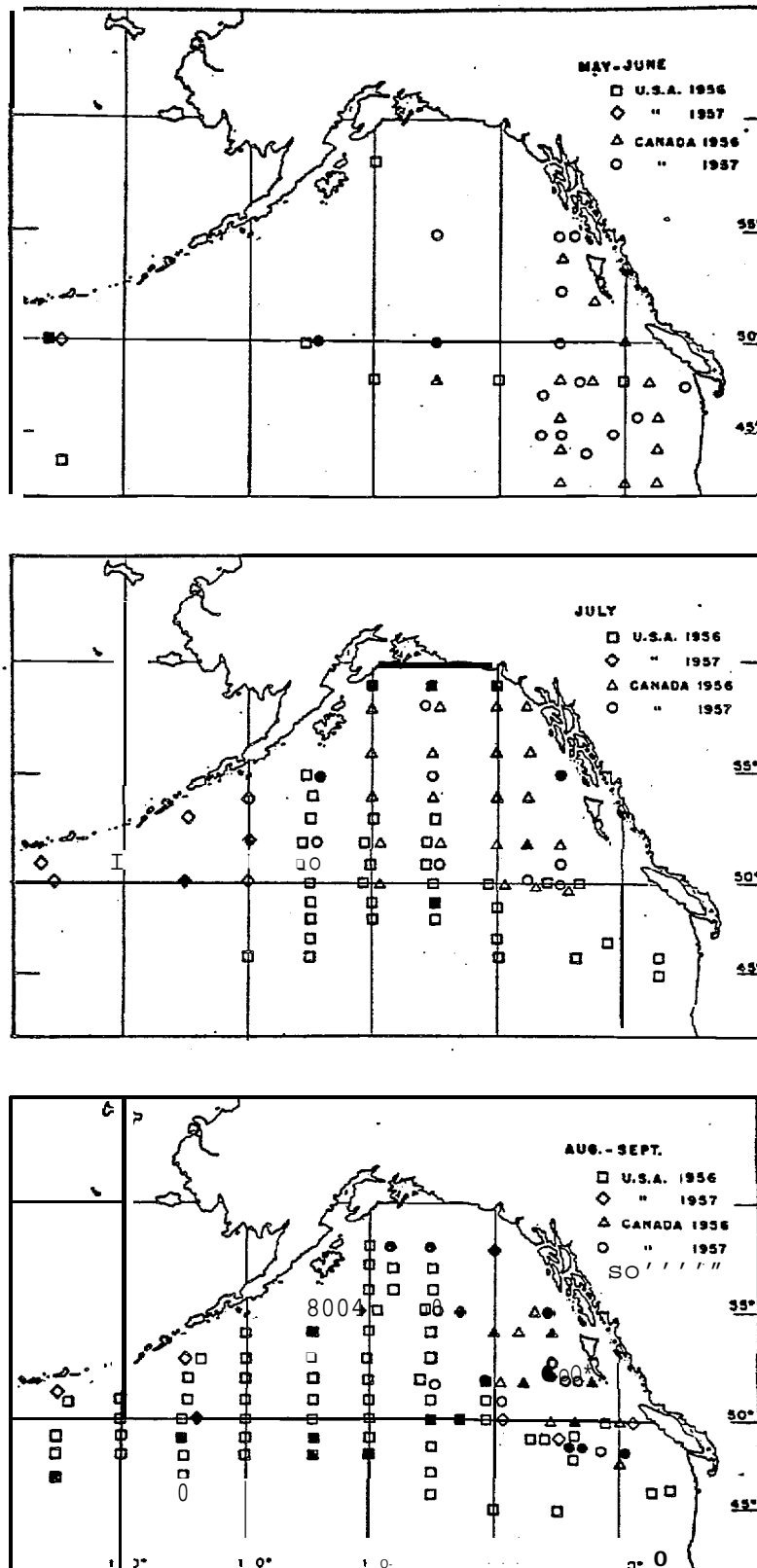
Figure III.2.2. —Distribution of **the** salmon shark
in gillnet catches **in** the Gulf of Alaska. **(Black**
symbols - occurrences, open symbols - fishing
stations where salmon shark were not taken.)
(From Neave and Hanavan 1960.)

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LIFE HISTORY

Reproduction

Little is known about the reproduction of salmon shark. The females
reach sexual maturity at about 5 feet (1.5 m), and a 6½ foot (2 III)
female caught in southern California contained four young, each weighing
18 pounds (8.16 kg) and measuring 30 inches (76 cm) in length (Herald
1961). Neave and Hanavan also refer to a record where four young were
produced, and Berg et al. (1949) state that the species is viviparous,
giving birth to two to five young.

Growth and Nutrition

Growth

The new-born salmon shark is 50-55 cm (up to 70 cm) in length (Berg
et al. 1949). Konstantinov (1968) stated that the salmon shark reaches
a length of 2 m at age 8 and 2.5 m at age 17. According to Berg et
al. (1949), it reaches a maximum length of 360 cm and more than 300kg
in weight.

Food and Feeding

The stomach contents of a male shark caught in Kachemak Bay (Cook
Inlet. Alaska) and examined by Bright (1960) included Pacific tomcod,
Microgadus proximus; sockeye salmon, Oncorhynchus nerka; parts of
a cottid, probably Hemilepidotus hemilepidotus; pink salmon, Oncorhynchus
gorbuscha; and chum salmon , O. keta.

Sano (1959, 1960, 1966) made extensive studies of the predation of
salmon shark on the salmons. He found that, at least during the season
when a fishery operated, there was a strong relationship between the
distribution of the shark and salmons, and the salmon were a high
percentage of the shark diet. About 70% of salmon sharks observed
had eaten salmon. Generally, the salmon species most abundant in an
area at the time and place the sharks were caught were those most
frequently found in the stomachs. In order of frequency of occurrence,
they were sockeye, chum, pink, coho and chinook salmon. Sano assumed
that each shark would feed on one to three salmon per day. He estimated
that more than 50,000,000 salmon may be Lost each year by shark predation
in the Aleutian area. In effect, what people consider a high quality
protein is converted to a low quality protein.

Aside from salmon, Sano (1959) noted the presence of squid; Atka mackerel,
Pleurogrammus monopterygius; Alaska pollock, Theragra chalcogramma;
lancet fish, Alepisaurus; lumpsucker, Eumicrotremus sp.; daggertooth,
Anotopterus sp.; herring; sauries; Sebastichthys; and some unidentified
species in sharks in northern areas. Sometimes these were intermixed
with salmon in the shark stomachs. The weight of stomach contents
ranged from 0.1 kg to 4.7 kg. Dogfish, myctophids, saury, and mackerel
also were found in shark stomachs in southern areas (Sano 1966). The

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diet apparently varies with different years and areas and availability of foods. Considering the size of the salmon shark and the energy it requires, Sano assumes a high digestion rate.

Physiology and Behavior-No information was available for this species.

Predators and Competitors

There are no known predators of the salmon shark (Sano 1959). Three wound areas noted by Bright (1960) on the lateral surfaces of a male shark captured in Kachemak Bay (Cook Inlet, Alaska) are unexplained but suggest the possibility of an unknown enemy.

Parasites and Diseases

Bright (1960) reported the presence of parasitic copepods, probably Chondracanthus, associated with the- wound areas mentioned above,. and the gills of a female were similarly infested. Shimazu (1975) found the adult form of the cestode, Nybelinia surmenicola, in the stomach of a salmon shark taken in the Bering Sea.

POPULATION STRUCTURE AND DYNAMICS

Sex Ratios in the Population

Sano (1960), reviewing L. ditropis catches by gillnet fishing operations of salmon motherships in 1959, stated that 248 sharks were examined for sex and 56,8% were found to be males. Females were more abundant south of lat 50° N and males were more abundant north of that latitude. Females were predominant in May to early July, but the proportion of males increased later in the season.

Size Composition

Sano (1960) conducted an extensive study of salmon sharks caught in 1958 and 1959 by catcher boats operating from 16 motherships licensed to fish with gillnets for salmon in areas west of long 175° W in the Bering Sea and North Pacific Ocean. He summarized the length-weight data for 49 specimens in 1959 as shown in Table 111.2.1. Total length measurements of 248 sharks (107 females and 141 males) by ten-day periods and by 2° of latitude are shown in Figs. 111.2.3 and 111.2.4. The average total length during the season was 207 cm for females and 208 cm for males. Body weight ranged from 70 to 180 kg but averaged about 100 kg. Smaller female sharks were caught in mid-July in areas north of lat 50° N. Males were larger and perhaps more abundant than females because so few females were included in the more northern samples. While these data were principally for sharks caught outside the defined areas for this report, they probably represent the length-weight relationships for salmon sharks that might be caught in the Gulf of Alaska and eastern Bering Sea.

Weight, (kg)	Length (cm) 150	160	170	180	190	200	210	220	230	240	250	260	70cm	Total
	2													2
60						1								1
70						1								1
80				2	3									5
90				1	4	1	2							8
100					2	2	3							7
110						1	1	1						3
120						2	3	5						10
130							1	1	3					5
140							1			1				2
150							1	1			1			3
160											1			1
170														
180														
190														
200										1				1
Total	2		3		9	8	12	8	3	2	1	1		49

Table 111.2.1.--Total length and body weight of salmon sharks in mixed
catches of salmon gillnets in the western Bering Sea and northwest
Pacific Ocean (one representative sample from mothership A). Individual
weights are accurate to $\pm$ 10 kg (from Sano 1960).
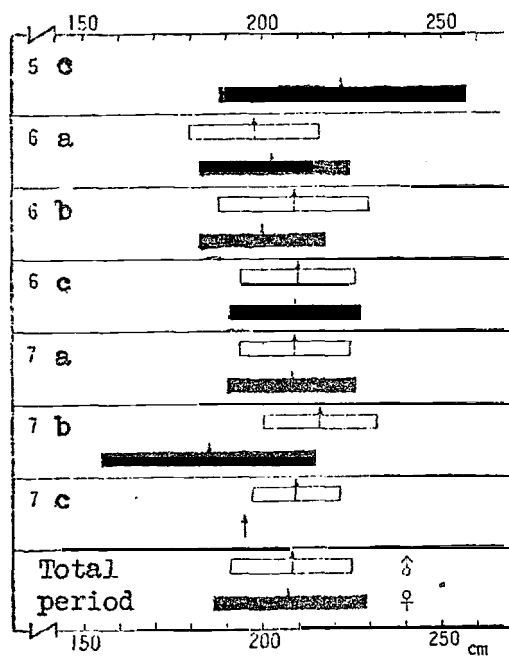
Figure 111.2.3
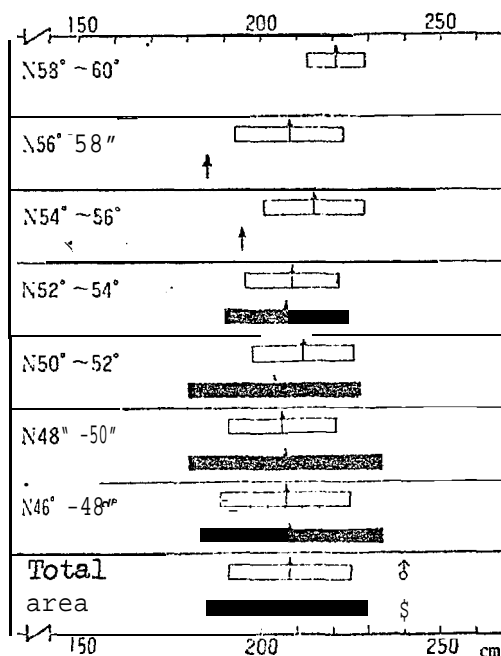
Figure 111.2.4

Figure 111.2.3. --Mean values and standard deviations of lengths of salmon
sharks caught by salmon gillnets in the western Bering Sea and northwest
Pacific Ocean, by ten-day periods and by sex in May-July. A-1st 10 days
of the month, b-middle 10 days, c-last 10 days (modified from Sano 1960).

Figure 111.2.4. --Mean values and standard deviations of lengths of salmon
sharks caught by salmon gillnets in the western Bering Sea and northwest-
ern Pacific Ocean, by 2° of latitude and by sex (modified from Sano 1960).

Bright (1960) gave some details on one male and one female salmon shark caught in Kachemak Bay in 1959. The male weighed an estimated 120 pounds (54.4 kg) and measured 67 inches (170 cm) from the snout to the end of the vertebral column. The female weighed an estimated 180 pounds (81.6 kg) and measured 76 inches (192 cm). No other information on size composition was found specifically for the Bering Sea and Gulf of Alaska as defined for this report.

Abundance and Density

Neave and Hanavan (1960) presented some information on the distribution of salmon sharks in the Gulf of Alaska in 1956 and 1957 as shown by catches of research vessels. Figure 111.2.2 reveals that the species was caught more frequently in August and September than in May through July. Larkins (1964) found a total of 172 salmon sharks were caught by research vessels using gillnets in the years 1955-61 in the Bering Sea, North Pacific Ocean, and Gulf of Alaska.

The abundance of salmon sharks caught in salmon gillnets of the Japanese mothership fleet in the western North Pacific and western Bering Sea apparently was much much greater but was the result of fishing with large quantities of gear (Sano 1960). Based on 20,518 catcher-boat days for 16 mothership fleets in 1959, the average catch per boat day for the season was 0.33. The catcher boats each set 10 to 15 km (330 to 364 tans) of salmon gillnets, and a number of hauls yielded more than 10 sharks.[1] The maximum catch, 40 sharks, was made by a gillnet of 330 tans. The frequency distribution of the average catch per boat day is shown in Fig. 111.2.5. More than 10,000 salmon sharks were estimated to have been caught during the season. No comparison of abundance between the Bering Sea and Gulf of Alaska can be made because the amount of gear used in the two areas was so drastically different.

Nothing is known of changes in density, recruitment, natural mortality and related subjects.

FISHING

According to Sano (1959), the' Japanese operated a longline fishery on salmon sharks in the general area between lat 40-44° N and long 155-165° E off the northeast coast of Japan. Berg et al. (1949) stated the Japanese catch of all shark species was 60,000 metric tons per year, of which the salmon shark was in second place after the spiny dogfish (Squalus acanthias). The catch in the Primorye region (Soviet Far East) up to World War II was 20-25 metric tons per year but may have increased by 1949 to several hundred tons per year according to Berg et al.

Berg et al. listed several types of gear used to catch the salmon shark. In Norwegian waters they are taken by floating longlines up to 17 km long fishing at night in depths of 100-300 m and baited with herring. In Japan, the shark is caught with gillnets and longlines, and in western Europe it also is caught with otter trawls and handlines. In Peter the Great Bay (U.S.S.R.) it is caught during sardine fishing entrapped in sardine driftnets, and it also is taken with hooks and harpoons.

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[1] A tan is a Japanese unit of gillnet length measure.

Catch of salmon shark (interval 0.2 fish)
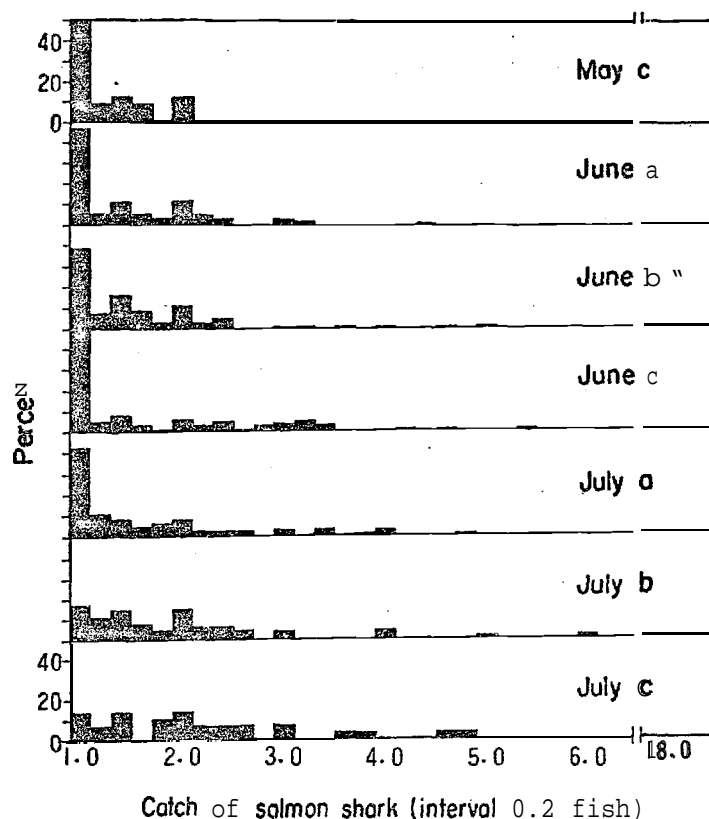
Figure 111.2.5.--Frequency distribution of catches of
salmon sharks per catcher-boat day by 10-day periods
in the western Bering Sea in May-July based on the
average catches of individual mothership fleets. A-1st
10 days of the month, b-middle 10 days, c-last 10 days
(modified from Sano 1960).

Even on research cruises the salmon shark is an unwelcome catch because
of damage to gear, difficulties in landing the catch, and the objection-
able work of opening the body cavity for organ examination.

FUTURE WORK

Because the salmon shark has been taken in commercial quantities in Japanese
and Russian fisheries in the western Pacific and was found in large quan-
tities in gillnets of salmon mothership fleets in the western Bering
Sea, the possibilities of future fisheries in the eastern Bering Sea
or Gulf of Alaska should not be dismissed. Potential fisheries will depend
upon the demand and market for the species plus a better knowledge of
its abundance, population dynamics, and ecological relations with other
fishes.

BLUE SHARK (Prionace glauca)
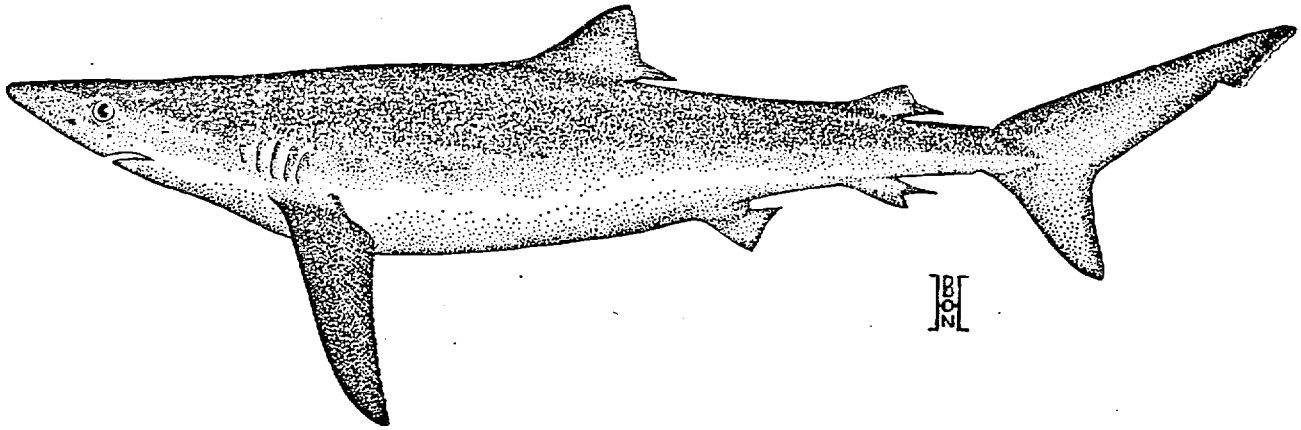
Figure 1-11.3.1.--Blue shark, Prionace glauca (from Hart 1973)..

IDENTIFICATION

Blue shark is the preferred common name for the selachian Prionace glauca
(Bailey et al. 1970). It is also known as the great blue shark and the blue
whaler. The common Japanese names are yoshikirizame, mizubuka, aobuka, or
aonagi; in Russian it is sinyaya akula, golubaya akula or mokoi. It commonly
reaches lengths of 2 to 3 m, but lengths to 25 feet (7.6 m) have been "reported
according to Clemens and Wilby (1935). Although Strasburg (1958) found some
difference in body measurements between blue shark caught in the Pacific
and "Atlantic Oceans, they apparently were not sufficient to separate into
unique groups.

DISTRIBUTION

The blue shark has a world wide distribution and is relatively abundant
in the temperate tropical and tropical oceans of the world including the
Mediterranean Sea (Hart 1973). It is found in the North Pacific Ocean, in
the mid-Pacific and in nearshore waters including Vancouver Island, the
Queen Charlotte Islands, the Gulf of Alaska and west to Japan. It has been
recorded in Puget Sound (State of Washington), and off the coasts of Wash-
ington and Oregon (Schultz and DeLacy 1935). There is no record of the blue
shark being in the Bering Sea.

.Parin (1968) stated that the greatest catches were made between lat 30-45°N
and generally where the temperature ranged from 7 to 15°C, and Strasburg
(1958) concluded that the species tended to favor temperatures between 7.2°C
and 20.6°C. At more southern latitudes, blue sharks were caught further
below the water surface than at more northern latitudes (Strasburg 1958,
Parin 1968) (Fig. 111.3.2).
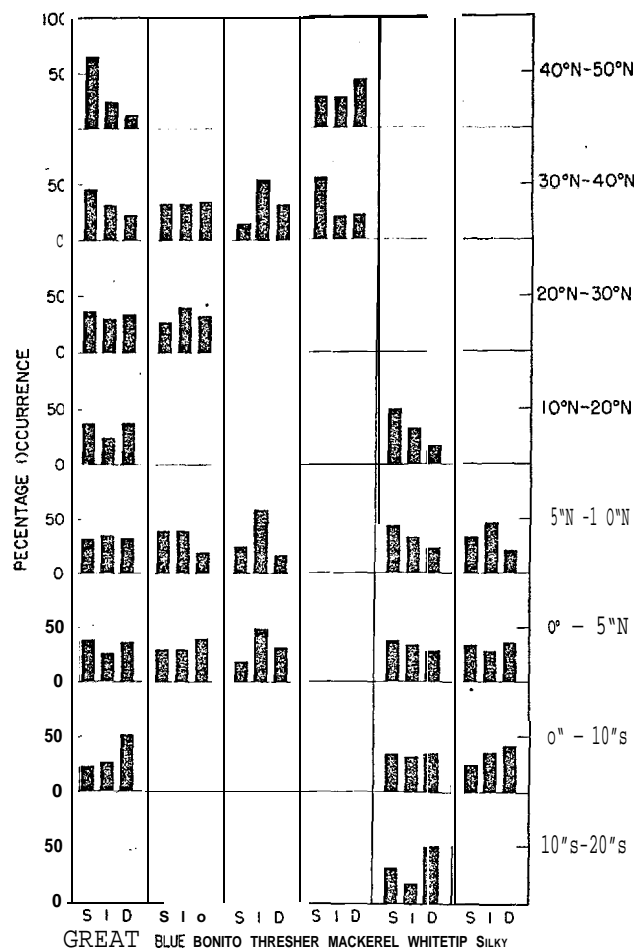
Figure 111.3.2 .--Vertical distribution of pelagic sharks by latitude.
Histograms depict percentage occurrence on shallow (S), intermediate
(I), and deep hooks (D). Data are basedon following catches: 1,318
great blues, 33 bonitos, 486 white tips, 311 silkies, 27 mackerels,
and 62 threshers (from Strasburg 1958).

Figure 111.3.3 shows the seasonal distribution of the blue shark in 1956
and 1957 in the Gulf of Alaska as described by Neave and Hanavan (1960)
from gillnet fishing by research vessels. The only blue sharks caught in
May and June were in the east and southeast sections of the Gulf. As the
season progressed, the northern boundary of catches moved northward and
to the west to reach a northern boundary at about lat 50°N and a westward
boundary that extended in a northeasterly direction from long 150°W and
lat 50°N almost to the coast of Alaska.

Larkins (1964) reported 877 blue sharks caught by research vessels in the
Bering Sea, North Pacific Ocean , and Gulf of Alaska in the period 1955-1961.
None was caught in the Bering Sea or Aleutian area, but they were classified
as abundant in the Pacific and southern Gulf of Alaska and rare in the
northern Gulf on the basis of catch per 100 shackles of gillnet.
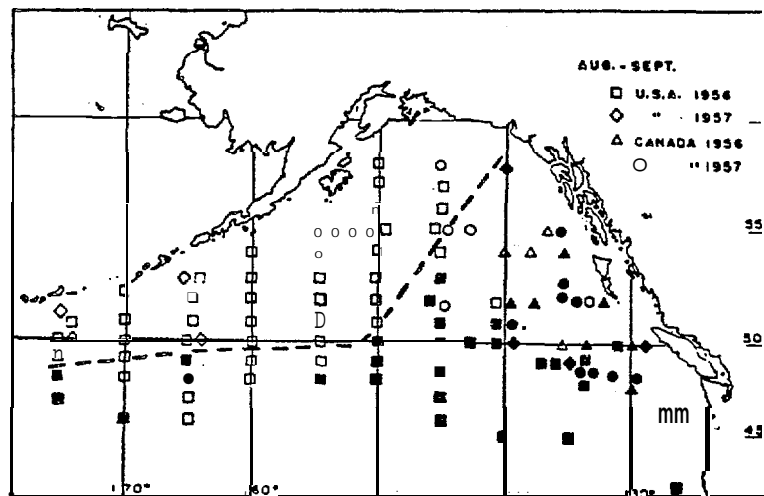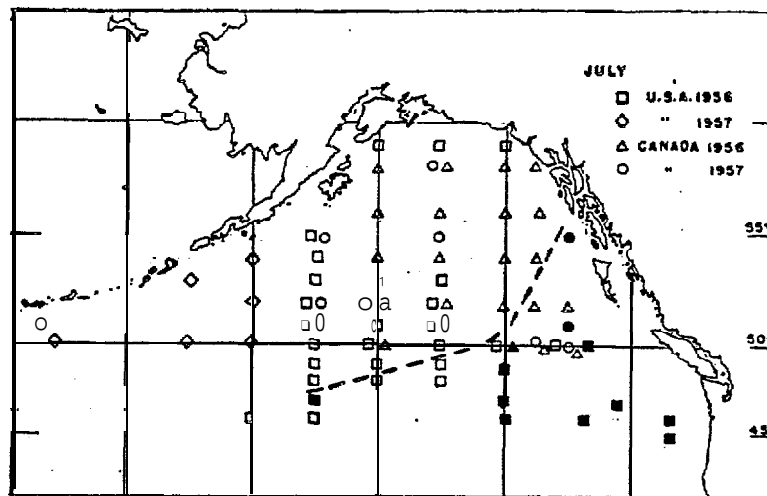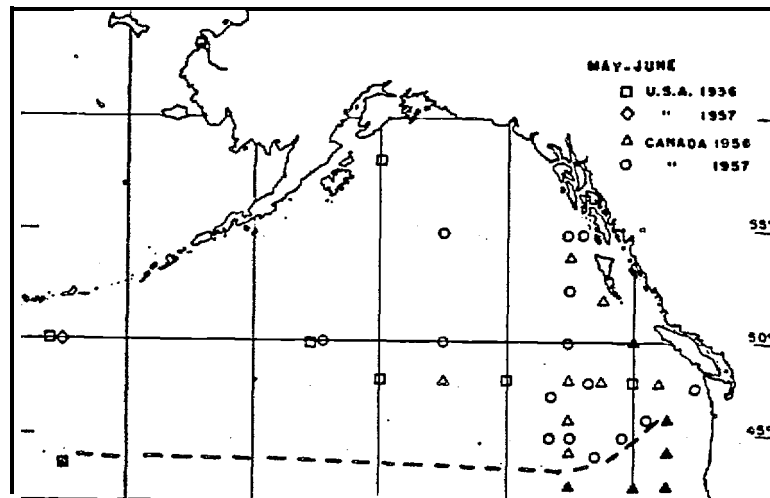
Figure III.3.3.--Distribution of the blue shark in gillnet
catches in the Gulf of Alaska, 1956-57. (Black symbols - .
occurrences, open symbols - fishing stations where blue
shark were not taken.) (From Neave and Hanavan 1960.)

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There is evidence of differences in distribution of blue sharks by latitude,
size area, and sex that appear related to season, temperature and reproduc-
tion. For example, the increased surface abundance of the blue shark in
the northern latitudes in summer is probably related to the seasonal increase
in food supply (Strasburg 1958).

LIFE HISTORY

Reproduction

The blue shark does not reach maturity until it has attained a length of
7 to 8 feet (2 to 2.4m), the young are born at lengths ranging between
18 (46 cm) and 21 inches (53 cm), and up to 60 may be born at one time (Hart
1973). Strasburg (1958) reported catching both gravid and non-gravid females, ,
throughout the year measuring from 208 to 247 cm. Parin (1968) stated that
young are born only in warm waters, and Strasburg found embryo-bearing females
only south of lat 35°N.

Much of the following information was taken from research by Strasburg (1958)
and Suds (1953) which was done outside the areas defined for this report,
but it is the only information available.

Strasburg (1958) showed a seasonal change in the abundance of blue shark
that appeared to be related to latitude (Figure 111.3.4). The peak observed
between. lat 40-50°N in the summer corresponded to the summer changes in
distribution and abundance observed by Neave and Hanavan (1960). According
to Strasburg the apparent increase in numerical abundance to the north was,
at least in part, due to the birth of young sharks because large numbers
of small blue sharks were captured in the spring, summer and fall seasons.
The smallest of these young sharks corresponded to the size of the large
embryos found in gravid females. Strasburg also pointed out that small blues
were rarely caught in warmer waters and that the northern seasonal migrations
may be a phenomenon of reproduction. Suds noted a marked difference in sex
ratio by season and locality; however, the data were not sufficient to allow
statistical evaluation of the differences.

Suds (1953) noted that the greater the distance from land, the greater the
tendency for males to be larger, and he found indications that some sharks
in more southern waters were somewhat larger than those from more northern
areas. The data in Table 111.3.1 indicate that the young are born from December
through April. Suds also determined that the gestation period for blue shark
is about 9 months and that the average number of embryos is about 30. The
natural sex ratio was about 1:1, and the smallest sexually mature females
were about 140 cm long.
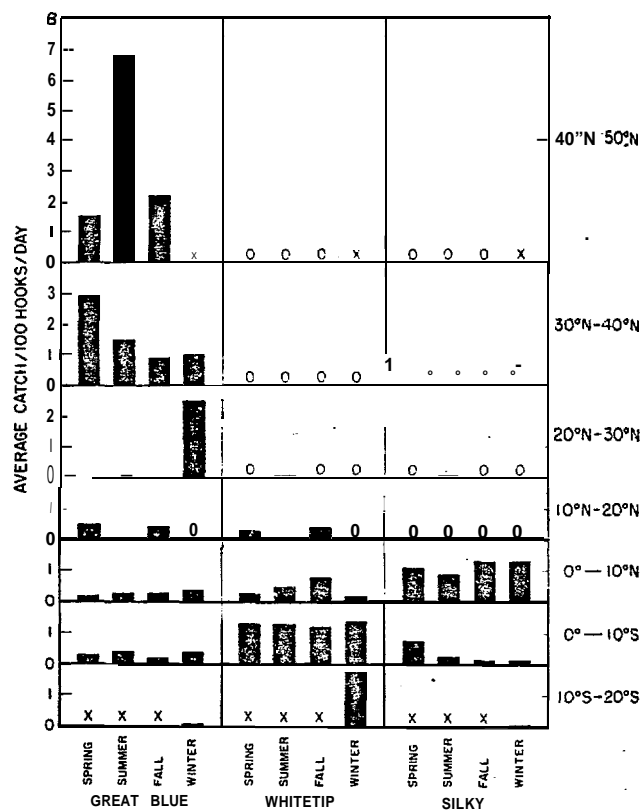
Figure 111.3.4.—Abundance of pelagic sharks by latitude and season. Based on 2,512 great blues, 1,187 whitetips, and 2,176 silkies. x = no fishing effort, 0 = no catch (from Strasburg 1958).

Table 111.3.1.—Length frequency of the embryo of the blue shark (from Suds 1953).

Month	Region	Length frequency (cm)								Total	mean length	S. D.
		0–5	5–10	10–15	15–20	20–25	25–30	30–35	35–40			
July	Southern seas	7	1							8	3.13	1.61
Aug.	" "	1	1							2	5.00	2.50
Dec.	Adjacent seas of Benin Is.	2	8	7	5	1	.	2		25	17.70	6055
"	Eastern seas of Japan					1	1			2	25.30	2.50
Jan.	Western seas of Midway Is.						1			1	27.50	
"	Eastern seas of Japan					2	1	2		5	27.50	4.47
Feb.	Adjacent seas of Benin 1s.				1	5	1	1	3	20	26.50	3.74
"	Eastern seas of Japan					"2	1	4		7	28.93	4.40
Mar.	Adjacent seas of Benin Is.							1		1	32.50	
"	Western seas of Midway Is.						6	17	2	25	"31.70	2.71
Apr.	" " "							1	2	3	30.83	2.40
"	Adjacent seas of Bonin 1s.						1			1	27.50	

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Because no satisfactory method of determining the age of the great blue shark has been found, no age-length nor age-weight data are available. The few scattered pieces of information on lengths and weights have been given above.

The blue shark feeds principally on pelagic and demersal fishes but also consumes some invertebrates. Strasburg (1958) stated that the great blue shark subsists on small fish, squid and occasionally on inedible objects. He noted that there appears to be a relationship between the distribution of zooplankton and sharks and a seasonal increase in the food supply in surface waters to the north that might also account for the seasonal increase in shark abundance to the north.

LeBrasseur (1964) found salmon (Oncorhynchus sp.), pomfret (Brama raii), saury (Cololabis pharao), squid, shrimp, lantern fish (Myctophidae), dagger. tooth (Anatopterus pharao) and salps (Salpa fusiformes) in the stomachs of great blue sharks taken in two gillnet catches in the southeast portion of the Gulf of Alaska. He also found evidence of selective feeding for salmon, since small jack mackerel (Trachurus symmetricus) and pomfret were available in the area but not included in the shark diet. The sharks he examined ranged in lengths from 76 to 137 cm (30 to 54 inches).

Nothing significant is known of predators and competitors, behavior and other facets of the biology and population characteristics with one exception--Budker (1971) found that a blue shark measuring 2 feet in length and weighing 1.3 pounds could swim as fast as 43 mph in a short burst of speed and could hold its position against water moving at a speed of 24.5 mph.

FISHING

The only reference to a commercial fishery found in the literature was made by Suds (1953), who collected some data from great blue sharks at the Tokyo fish market. He did not identify the places they were caught or the types of gear used , and the commercial value of Japanese catches is unknown.

The blue shark has been a nuisance to North American fishermen in their attempts to develop long line methods of catching albacore according to Powell and Hildebrand (1950), and sometimes it is caught incidentally in other "types of gear used in North American waters.

POTENTIAL CONTRIBUTION TO DOMESTIC AND INTERNATIONAL ECONOMY

Because the livers are small, the vitamin A potency is low, and few North "Americans will eat shark meat, there is little likelihood of the species becoming of significant commercial value. If changing technology should find new methods of using the blue shark or if demands for protein increase to make fisheries feasible, then the blue shark might support a modest fishery.

SPINY DOGFISH (<u>Squalus acanthias</u>)
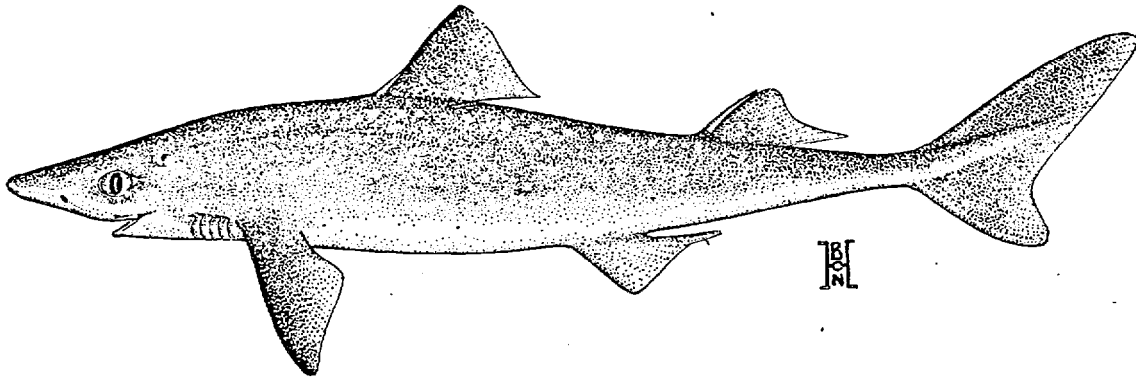
Figure III.4.1.—Spiny dogfish, <u>Squalus acanthias</u> (from Hart 1973).

IDENTIFICATION

Several different common and scientific names have been used for the spiny
dogfish, <u>Squalus acanthias</u> Linnaeus 1758, according to Hart (1973). At
one time the accepted scientific name was <u>S</u>. <u>suckleyi</u> (Girard 1854). The
preferred common name is spiny dogfish (Bailey et al. 1970), but some
other common names are dogfish, California dogfish, mud shark, and piked
dogfish. At times, it has been marketed under the names grayfish and flake.
Common Japanese names are aburatsunozame, aburazuno, hozame, mukizame
and aburazame (Berg et al. 1949, Okada and Kobayashi 1968). Russian names
include kalyuchaya akula and morskaya sobaka (Berg et al. 1949).

Morphological differences exist between spiny dogfish caught in the Atlantic
and Pacific Oceans, but they are not sufficient to identify a separate
subspecies (Hart 1973).

Jensen (1966) reported that serological studies carried out on dogfish
from the Gulf of Maine showed the existence of different antigens. Similar
studies in the Pacific Ocean might show differences that might be regional
or possibly result in a separation of the Atlantic from the Pacific spiny
dogfish.

Foster (1943) was of the opinion that the migrations of the coastal spiny
dogfish in the eastern Pacific Ocean, as shown by tagging, resulted in
a mixing that probably produced only one stock of dogfish in the area
from California to southern British Columbia. Fedorov (1973a), however,
separated the spiny dogfish found from southeastern Alaska to southern
California into a subspecies , <u>S</u>. <u>acanthias suckleyi</u>, separate from the
dogfish found in the Bering Sea, giving no reasons for the separation.

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DISTRIBUTION

The spiny dogfish is found from Baja California north to the Bering Sea
in the eastern Pacific Ocean and in the Aleutian Islands, along the Kamchatka
Peninsula, and off Japan to northern China in the western Pacific (Wilimovsky
1954, Rass et al. 1955, Grinols 1965). In the Atlantic Ocean, it is distri-
buted in coastal waters of the United States and Europe, and it is found
in the Mediterranean and Black Seas (Hart 1973).

Alverson, Pruter, and Ronholt (1964) reported in their studies of demersal
fisheries in the northeastern Pacific Ocean that the number of species
of elasmobranchs decreased in the more northern latitudes and none was
found in the Chukchi Sea. They-found the dogfish in all depth zones to
399 fathoms (732 m) along the west coast of the United States and Canada
and the Alaskan Peninsula. There were fewer spiny dogfish among the total
elasmobranch catches in areas west and north of Cape Spencer, southeast
Alaska. Also, the percentage of occurrence of dogfish in the total catches
of trawls declined in the more northern waters. The catch per unit of
effort was highest south of Cape Spencer and greatest in the Strait of
Juan de Fuca, Washington. Dogfish were relatively common in Prince William
Sound and less con-anon in Shelikof Strait. Centers of dogfish abundance
in the eastern Pacific included Puget Sound (Washington), the Strait of
Georgia (British' Columbia), and the Continental Shelf from central Washington
to Hecate Strait. Large concentrations apparently occurred during spring
and "summer off Washington and British Columbia."

The spiny dogfish was considered a common species taken during experimental
salmon fishing in the southern Bering Sea, Aleutian Islands and North
Pacific Ocean, and the Gulf of Alaska in 1955-61 (Larkins 1964), The fish
was considered common on the basis of catch per 100 shackles of net being
between 1-10 in any area. Bean (1889) wrote that the dogfish was so common
in the Gulf of Alaska that fishermen considered it a nuisance.

Alverson et al. (1964) found dogfish to be largely sublittoral, and their
abundance was greatest on the inner continental shelf and out to 199 fathoms
(365 m). Grinols (1965) said they were benthic and abundant in subarctic
and temperate waters from 1 to 400 fathoms (732 m) off Alaska, British
Columbia, Washington, and Oregon. Fedorov (1973a) listed the distribution
in the southern Bering Sea as ranging from sublittoral depths down to
230 m.

Spiny dogfish seem to like relatively high temperatures, mostly between
4 and 15°C, particularly between 8 and 12°C (Kasahara 1961). Incidental
catches of five fish by Hanavan and Tanonaka (1959) in the Bering Sea
and Gulf of Alaska in July and August were in water temperatures of 7
to 13*C.

The distribution of spiny dogfish in the eastern Bering Sea 'and Gulf of
Alaska based on our analysis of historical catch data is shown in figures
'in Section IV, Historical Data Record of Non-salmonid Pelagic Fishes.

LIFE HISTORY

Reproduction

Spiny dogfish are slow to mature, and males mature at a smaller size than females. Off the Washington coast, spiny dogfish males at maturity were age 11 and 72 cm long, and females were age 19-20 and 92 cm (Bonham et al. 1949). Ketchen (1972) found that 50% of females were mature off British Columbia at 93.5 cm length. In the western Pacific, Kaganovskaya (1937) did not find mature females less than 19 years old or less than 100 cm, and Yamamoto and Kibezaki (1950; cited by Ketchen 1972) concluded the usual length of males at maturity was between 70 and 80 cm, Ketchen presents an excellent review of spiny dogfish in British Columbia waters related to literature by various other investigators in both the Pacific and Atlantic Oceans.

The spiny dogfish is ovoviviparous, the eggs of the female being fertilized internally by the male's claspers and the young are born alive (Jensen 1966). The breeding season is apparently December to February in the eastern Pacific, although the exact time of mating is difficult to determine (Bonham et al. 1949, Ketchen 1972). According to these authors, mature eggs (3-4 cm in diameter) pass. from the ovary through the shell gland where they are simultaneously fertilized and encapsulated in a gelatinous protective shell. The capsule is dissolved or shed before the young are born, the gestation period within the female lasting nearly two years. The young are born in October-December in the northeast Pacific.

The number of embryos per female is 2-17 and averages 6-7 in the eastern Pacific. In the western Pacific near Sakhalin Island, Kaganovskaya (1937) . found the number to be 5-19, with an average of 11. A weak correlation was found between the numbers of embryos produced and the length of the female, according to Ketchen. Sex ratios of pups during development in the female are approximately 1:1 in Washington waters (Bonham et al.1949) as well as in the Gulf of Maine (Jensen 1966).

Growth and Nutrition

Growth

No length, age, and weight data were found for the specific areas defined for this report. Consequently some data for both the eastern and western Pacific Ocean are presented since they probably describe or overlap 'the range of growth relationships that would be found in the defined areas.

As mentioned previously, growth of the spiny dogfish is very slow. The average length of embryos in the northeastern Pacific by the end of the first year is 14-15 cm, and the embryos at that time are still wholly dependent for sustenance on a large external yolk sac (Ketchen 1972). The size range at birth is 24-30 cm and averages 26-27 cm (Bonham et al. 1949, Ketchen 1972). Ketchen presents a figure comparing mean length and range of lengths of dogfish embryos at various stages of development in both the Pacific and Atlantic Oceans.

Growth is difficult to determine because traditional methods of age determination cannot be applied to dogfish. A technique devised by Kaganovskaya (1933), counting annulations on the spines of the dorsal fins, has been adopted by other scientists, although the accuracy is questionable. Using this Russian method, Bonham et al. (1949) estimated dogfish in Washington waters grew 3.1 cm per year as compared with a rate of 3.5 cm per year which they found in a study of eggs and embryos, a rate·of 3.3 cm per year from length-frequency studies, and a rate of 1.4 cm per year in tagging studies. The most rapidly growing dogfish grew 7,5 cm in a year. Holland (1957) found the annual growth of tagged dogfish in the northeast Pacific was 2.3 cm, and he concluded, as did Bonham et al. and other investigators, that tagging may affect the normal growth rate. Kaganovskaya's (1933) data from dogfish near Sakhalin suggested an annual growth of 3.5 cm, similar to that found by Bonham et al. The two growth rates from interpretation' of spine markings by Kaganovskaya and by Bonham et al. are shown in Fig. 111.4,2. The similarity in growth between dogfish caught in Washington and those from the Okhotsk and Japan Seas is evident from comparing Table III.4.1 with Table 111.4.2. Age-length relationships found by Kaganovskaya in Japanese waters are given in Table 111.4.3.

The maximum length of males on both sides of the Pacific Ocean was approximately 100 cm and the maximum for females was 130 cm (Ketchen 1972). Bonham et al. found maxima of 100 cm and 3.6 kg for males and 124 cm and 9 kg for females off the Washington coast. The maximum age of the spiny dogfish is 25-30 years according to Jensen (1966)..
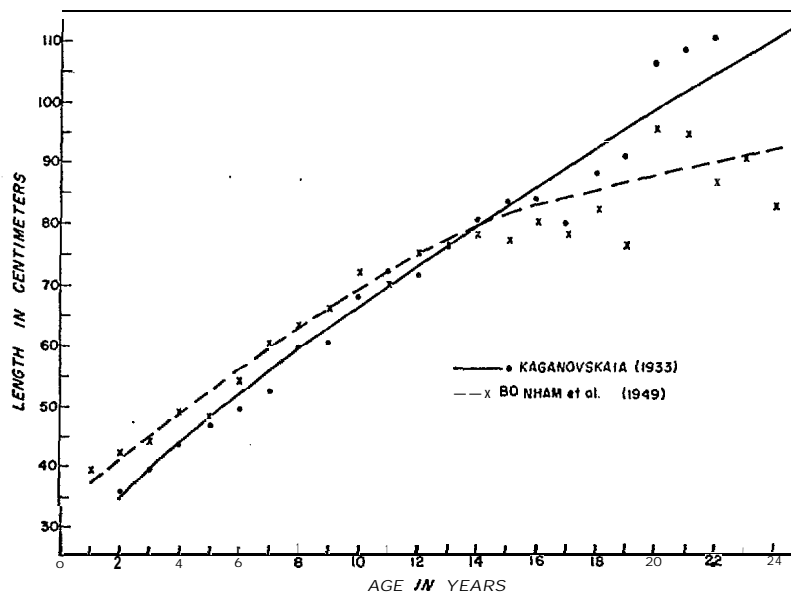
Figure 111.4.2.--Two growth rates for the spiny dogfish based on interpretation of spine markings (from Jensen 1966).

Table 111.4.1.--Relationship of number of annulations on selected spines to lengths of Washington dogfish (n=215). (From Bonham et al. 1949).

Number of annulacions	Length of dogfish in centimeters																							Number (n)	Mean (M)
	34	39	42	46	50	54	58	62	66	70	74	78	82	86	90	94	98	102	106	110	114	118	122		
1	5	5	1																					11	39
2		8	6	1	2	1																		18	42
3		b	6	5	1	1	1																	18	44
4			4	4	2	1							1											12	49
5			1	3	2	2																		8	48
6			1	4	2	1	1	2	1	1														13	54
7				1		2	4	1		1	1													10	60
8				2	2	1	2	2	1	1			1											12	63
9				2			2	4	1	4	2		1	1										17	66
10					1	2	1						1											5	72
11						2		4	3	3		2												14	70
12						2	2	2	5		2													13	75
13						2	1	2	1	2	1		1											10	77
14							2		3	2														7	78
15					2		2	1	2		1	1		1										10	77
16					1		2	1		2	1		1											8	80
17						2	1			2		1												6	78
18							1	1	1	1	2													6	82
19							1	1																2	76
20							1	1				1												3	95
21												1												1	94
22									1		1													2	96
23											1													1	90
24								1																1	82
25											1				1		1							3	111
26														2										2	106
27															2									2	110
28																									
29													1											1	106

Table 111.4.2.--Age composition and average size of dogfish (n=210) in the vicinity of the Sea of Okhotsk and the Sea of Japan (from Bonham et al. 1949, citing Kaganovskaya 1933).

Years of Age	Length of dogfish in centimeters																							Number (n)	Mean (M)
	34	38	42	46	50	54	58	62	66	70	74	78	82	86	90	94	98	102	106	110	114	118	122		
2		7																						7	36.0
3		4	5	1	1																			11	39.6
4				8	1	5	6																	29	43.7
5			2	10	24	3																		39	46.8
6				3	s		5	1	1															18	49.5
7				1	4		6	1	2.1															15	52.5
8						2	3	7	2															14	59.7
9						5	1																	6	60.6
10								1	1	1														3	68.0
11								2		4	2	1												9	72.0
12								3	3		4	2												12	71.6
13								1	2	1	1				1									6	76.0
14									2	1		1	1	1										6	60.6
15									1		1	2	2	1										7	83.4
16									1		3		1											5	84.0
17									1	4	1													6	80.0
18									1		1	1	1											7	88.0
19										2		1			1									4	90.5
20														1(?)										3(?)	106.0
21														3(7)										1(?)	10s.0
22																	1							1	110. Q
23																									
24																									
25																		1						1	118.0

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Table 111.4.3 .--Age- length relationships of spiny dogfish in Japanese
waters (from Kaganovskaya 1937).

Age	\multicolumn{21}{c}{Length (cm)}	n	M.
	380	420	460	500	540	580	620	660	700	740	780	820	860	900	940	980	1020	1060	1100	1140	1180		
2	7																					27	360
3	4	5	1	1								+										11	200
4		8	15	6																		29	427
5		2	10	24																		39	468
6			2	8	5	1	1															18	495
7			1	4	6	1	2	1														15	525
8					2	3	7	5														14	597
9							5	1														6	606
10								1	1	1												3	680
11							2		1	4	2	1										9	720
12							3	3		4	2											12	716
13								1	2	1	1		1									6	760
14									2	1		1	1	1								6	806
15								1			1	2	2	1								7	834
16									1			2		1								5	840
17									1	2	1											6	800
18											1		1	1	1							4	880
19												2		1			1					4	905
20																		3				3	1060
21																		1				1	1080
22																			1			1	1100
23																							
24																						1	1180
25																							

Food and Feeding

The spiny dogfish feeds primarily on fish but also has large proportions
of invertebrates in its diet at times. They are opportunistic feeders
rather than discriminatory predators (Chatwin and Forrester 1953, Jensen
1966, Taylor 1970).

Feeding studies in Washington State waters showed that 59% of the stomachs
of more than 1,100 spiny dogfish contained food (Bonham et al. 1949, Bonham
1954). Fish comprised about two thirds of the diet, one-sixth was shellfish
and the remainder consisted of other marine organisms and unidentifiable
material. Ratfish (Hydrolagus colliei) composed 20%, herring Clupea harengus
pallasi) 18%, and euphausiids about 9% of the diet. Very small dogfish
contained worms and other bottom living forms of life. No relationship
could be found between the type of diet and the amount of vitamin A in
the liver.

Chatwin and Forrester (1953) examined the stomach contents of spiny dogfish
caught near the mouth of the Fraser River in the spring months, All of
the stomachs containing food included eulachon, Thaleichthys pacificus,
and usually they were the principal food. A large number (21%) contained
sticks and leaves. Other food items included sand lances (Ammodytes),
hake, whiting, steelhead, salmon, smelts, yellowshiners,blennies,eel
pouts, flatfish, round fish, fish eggs, eulachon eggs, various invertebrates,
even a honey bee, and bottom dwelling worms. The diet of dogfish outside

the river mouth in other coastal areas was much the same, but included herring, crab, shrimp, octopus and squid, and schizopods in addition to those items mentioned above. Food in the dogfish from Hecate Strait and the Strait of Georgia was chiefly fish, while dogfish stomachs from the west coast of Vancouver Island contained mainly shrimp. Some of the differences were because samples were taken in different seasons.

During surveys off British Columbia in 1969-70, Taylor (1970) found dogfish feeding mainly on euphausiids, the proportion varying with the area of catch and the length of the fish. Other foods, also varying by area and percent, were herring, eulachon, sand lances, lantern fish, amphipods, combjellies, and hellyfish.

On the western side of the Pacific Ocean, Kaganovskaya (1937) stated that the dogfish followed and ate from schools of herring in the spring, then shifted to other food. Dogfish food was extremely varied and included herring, iwashi (sardine)? cod, octopus, crab, squid and sea cucumbers, the food types illustrating that sharks feed from the surface waters to the bottom. No definite seasonal migrations could be established except a seasonal vertical change related to food.

Konstantinov (1968), reviewing literature about the biology and life history of sharks, cites references to the importance of the sense of smell to sharks in finding food and also mentions that low frequency sound waves may be used to find food.

Predators and Competitors

Jensen (1966) stated that the spiny dogfish have few enemies and evidences of cannibalism are seldom seen. Predators are mainly large fish and large sharks. Known predators of record include the mackerel shark (Lamna nasus), the maneating shark (Carcharodon carcharias), the tiger shark (Galeocerdo cuvier), the blue shark (Prionace glauca), the barndoor skate (Raja laevis), the lancetfish (Alepisaurus ferox), the tuna (Thunnus thynnus), the tilefish (Lopholatilus chamaeleonticeps), and the goosefish (Lophius americanus).

Marine mammals consume some dogfish. Fisher and MacKenzie (1955) found dogfish remains in the grey seal (Halichoerus grypus) and in the killer whale (Grampus orca). Dogfish have also been recorded in the stomachs of the sperm whale (Physeter macrocephalus) taken in the Kurile Islands (Betesheva 1961) and in the Bering Sea (Sleptsov 1952) according to Berzin (1971). Geptner [Heptner] et al. (1976) stated that Sleptsov (1955) and Tomilin (1957) had listed dogfish as food of the harbor porpoise (Phocaena phocoena) in the northeast Pacific Ocean. Spiny dogfish were found in the stomachs of fur seals (Callorhinus ursinus) taken along the coast of California between lat 41° and 42°N in 1961 according to the North Pacific Fur Seal Commission (1962).

Parasites and Diseases

No information was found on diseases and only one reference to parasites
was noted. Chatwin and Forrester (1953) mentioned that in examining food
contents of dogfish stomachs in the Fraser River estuary, there were a
number of occurrences of parasitic worms not classified as food. Trematodes
and cestodes were true dogfish parasites, but nematodes and a parasitic
copepod probably came from fish remains that were present.

Physiology

Bonham et al. (1949) made a study of the vitamin A content of the livers
of the spiny dogfish. They found the livers of mature females contained
a lower percentage. of oil but the oil had a higher vitamin A potency than
in the livers of immature females. No evidence of regional variations
in vitamin A potency was found between dogfish caught in inside waters
compared to those caught in outside waters in Washington. There was a
seasonal trend for vitamin potency to be highest in the January-March
period and lowest in the July-September period.

Behavior

Migrations

Data from extensive tagging programs indicate that along the Washington
Coast spiny dogfish tend to migrate northward in the spring and summer
and southward in the fall and winter (Bonham et al. 1949, Holland 1957),

Holland (1957) concluded that there was evidence of an indigenous dogfish
population in Puget Sound and the Strait of Georgia and a migratory coastal
population ranging from Baja California north and west to Japan. Approxi-
mately 75 percent of tag recoveries were made in the same area of release.
The data also indicated there was little mixing of the populations in
Puget Sound and the Strait of Georgia.

Some examples of noteworthy migrations of spiny dogfish were obtained
from the tag recoveries. A tagged fish released in August 1944 southwest
of Ucluelet, B.C., was recovered more than seven years later south of
San Francisco Bay, having travelled more than 700 nautical miles and grown
14 cm (Kauffman 1955). Another fish, although not migrating a long distance,
was recovered 80 miles from the point of tagging nearly 10 years after
being tagged. The most spectacular" recovery mentioned by Kauffman was
a fish released off Willapa Bay in October 1944 and recaptured more than
seven years later in February 1952 off Honshu Island, Japan, after traveling
a minimum of 4,000 miles.

Some evidence on catches during the summer by different gear in the western
Pacific shows that surface and bottom layers of water are characteristic
. for sharks of different ages, sizes, and sexes (Kaganovskaya 1937). Holland

(1957) similarly noted that tagged females in the eastern Pacific tended
to be caught in fishing gear operating in the upper or intermediate water
levels while males tended to be caught in deeper waters in trawls,

For the western Pacific Ocean, Kaganovskaya (1937) reported the movements
of dogfish were dependent on the movements of their feed. In the spring,
they followed the herring first, then shifted to other foods,

Schooling

According to Jensen (1966), young dogfish tend to school together from
birth to time of attaining sexual maturity, but mature adults tend to
school by sex. Jensen lists research done in the Atlantic Ocean where
sex-size segregated schools were found, and he notes that this phenomenon
probably is found in the eastern Pacific despite reports to the contrary.
Quigley (1928) found that schools off Vancouver Island consisted of both
sexes and all sizes of fish, but larger fish usually were taken at a greater
depth. Data from Bonham (1954) supported Quigley's conclusions. Work by
Kaganovskaya (1933) in the western Pacific, however, in which she observed
schools segregated by sex, size, age, and depth, agree with those from
other areas.

POPULATION STRUCTURE AND DYNAMICS

Sex Ratios in the Population

No information was found on the sex ratio in commercial catches in the
subject areas, but some data are available from scientific research. The
sex ratio of spiny dogfish pups at birth is presumably nearly 1:1, but
the sex ratio of adults is difficult to determine because of their schooling
habits (Jensen 1966). In tagging operations, Holland (1957) tagged approxi-
mately equal numbers of both sexes in the Strait of Georgia, B.C., and
Puget Sound, Washington, waters, but" males predominated off Vancouver
Island, B.C., and females were dominant in Willapa Bay, Washington. Holland
concluded that the evidence indicated that females predominated in drift
gillnet catches and that males predominated in otter trawls in coastal
Waters, showing differences in depth distribution by sex.

Kaganovskaya (1937) presented a correlation of sexes of spiny dogfish
by different gear and of embryos in the western Pacific:

Fishing gear	Percent males	Percent females	Number
Set nets	47.3	52.6	598
Iwashi (sardine) nets	14.7	85.3	122
Bottom nets	87.8	12.2	266
Embryos	49.7	50.3	173

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She concluded that, at least in summer, "mature females and young dogfish are found in upper water layers and near the bottom in shallow depths, while males live in lower layers at greater depths. Chatwin and Forrester (1953), sampling spiny dogfish at the mouth of the Fraser River during spring months, found males outnumbered females by 9 to 1, a fact " ... consistent with the known habit of dogfish congregating according to sex and size.."

Size and Age Composition

Analyses of size and age composition of commercial catches in the subject areas were not found in the literature, but some information on the species was found in reports of research and scientific sampling. Some data have already been presented in the section on "Growth," and age-length relation-ships of spiny dogfish in Japanese waters (Kaganovskaya 1937) are shown in Table 111.4.3.

As mentioned previously, ages of spiny dogfish are difficult to determine, and sizes of fish captured vary with types of gear used. Kaganovskaya's analyses of catches by different types of gear in the western Pacific showed that bottom nets, which had a mesh of 7.5 cm, were selective and caught fish from 60 to 116 cm, averaging 100, 87.8, or 94.8 cm, depending upon the area. Set nets caught young fish from 34 to 100 cm, averaging 71 or 50 depending upon the area. Catches in iwashi (sardine trammel) nets were of fish of random lengths. Bottom nets caught fish mainly of older age groups with a predominance of males; set nets caught younger age groups, both males and females; and iwashi nets caught predominantly females of younger age groups, very infrequently males and larger females.

The age composition of the fish analyzed by Kaganovskaya also varied with the gear used. Bottom nets caught older fish of ages 10 to 19, set nets caught fish predominantly of ages 4 to 8, and iwashi nets caught dogfish of all ages from 2 to 25 years.

Abundance and Density

Relative abundance and distribution of spiny dogfish by gear and by season as determined by our analysis of exploratory fishing and sampling of various agencies is shown in Section IV, Historical Data Record of Non-salmonid Pelagic Fishes.

Alverson (1968) included the spiny dogfish among the ten most common demersal fishes in the northeast Pacific Ocean and stated the species has a large potential for increases in production. He estimated the standing stocks off Washington and Oregon (Transition Zone) as being 450,000 tons and those of the Gulf of Alaska as 25,000 tons. The elasmobranchs (dogfish, ratfish, skates, brown catshark, and electric rays) decreased with increasing depth, and the number of species decreased in more northern waters (Alverson et al. 1964). According to the latter authors, the dogfish comprised 44 to 78 percent of elasmobranch catches by depth zone in the Oregon-Washington region and totalled 74 percent of the elasmobranch catch in the 50 to 99-fathom depth interval in the British Columbia-southeastern Alaska region.

The importance of the dogfish in the elasmobranch catches dropped rapidly in waters north and west of Cape Spencer, Alaska, and in drags made in the Alaska Peninsula region. Catch per unit of effort was highest south of Cape Spencer on the continental shelf but much reduced north of Cape Spencer. Dogfish were relatively common in Prince William Sound, but catch rates decreased in Shelikof Strait.

Larkin and Ricker (1964) estimated the stock of dogfish in British Columbia as being between 500 million and a billion pounds at the time of their writing. Their estimate of the original stock before intensive fisheries in the 1940's was on the order of one billion pounds. Shepard and Stevenson (1956) estimated that the weight of the dogfish population off the British Columbia coast exceeded the weight of all other groundfish. Alverson et al., , (1964) were of the opinion the surveys in shallower waters off the coasts of British Columbia and Washington were inadequate, however, to allow estimation of magnitudes. Alverson (1968) estimated the maximum sustained yield of spiny dogfish in the northeast Pacific Ocean as 20,000-30,000 tons per year,

Alverson and Stansby (1963) pointed out that even during the years of intensive fishing for dogfish in the 1940ls actual changes in stock abundance were masked by other changes including economics, gear efficiency, and fishing intensity. The available information does suggest that there 'as a marked reduction in abundance as a result of fishing. Supporting information came from fishermen who were of the opinion that dogfish were no longer as abundant in some areas where they had been fished. Some data indicated a decline in catch per unit of effort, a reduction in the pounds of livers landed, and a removal of older age classes. In the years following chemical production of vitamin A and the decrease in fishing intensity, dogfish appeared to increase in abundance in some areas. Shepard and Stevenson (1956) stated, "In consequence of the cessation of fishing for dogfish, the stock now appears to "be in the process of a strong recovery. Already, the dogfish has become a plague on many of the British Columbia fishing grounds— disrupting the, trawl and seine fisheries for other species."

Alverson and Stansby noted that the life history of the dogfish is not conducive to rapid buildup of the stocks. Similar observations were made by Holden (1974) in a study of the exploitation of elasmobranchs in 'he Atlantic Ocean. He pointed out that fisheries for several species of shark had revealed some general characteristics--a fast rise in catch to a peak, then a rapid decline followed by a slow recovery. He attributes this to a combination of high age at maturity, slow growth and the small numbers of young born to each female.

Population/Ecosystem Relations

Very little information was found on population and ecosystem relations. Alverson et al. (1964) included tables of catches of elasmobranchs and six other fishes by area and depth intervals of 50 fathoms from 1-49 to 500-599. These tables showed the distribution and abundance mentioned previously.

Chatwin and Forrester (1953) found a close relationship between the catch per unit of effort of eulachon and the total catch of dogfish off the mouth of the Fraser River. The association of schools of herring, hake dogfish, and salmon as measured by tows on three cruises off British Columbia was discussed by Taylor (1970). Dogfish in combination with herring and/or salmon was in many cases the dominant contributor.

FISHING

History of the Fishery

The history of fisheries for spiny dogfish on the Pacific coast is described by Harrison and Samson (1942), Barraclough (1953), and Alverson and Stansby (1963). Fisheries of both the Atlantic and Pacific Oceans are discussed . by Jensen (1966).

Spiny dogfish have been taken by aboriginal people of the eastern Pacific for food and oils from before recorded history, and early white settlers in the Pacific Northwest used the oils for many purposes (Alverson and Stansby 1963). The dogfish was considered to have little commercial value, and early attempts to use dogfish as food in this country were unsuccessful. Most commercial catches were incidental to other fisheries, and the fish were reduced to oil and to meal for chicken feeds.

The fishery expanded rapidly in the eastern Pacific when the outbreak of World War II in Europe in 1939 cut off imports of cod liver oil and created a demand for new' sources of vitamin oils. Shark and dogfish livers were excellent sources of vitamin A. The dogfish fishery of the Pacific Northwest reached a peak in 1944 when 133 million pounds of whole fish were caught between California and Alaska (Alverson and Stansby 1963). After 1949, imports of oils and production of synthetic vitamin oils caused reduced demand for dogfish livers and the fishery decreased to its present low level of several million pounds.

The gear used to catch spiny dogfish in the eastern Pacific has evolved from simple handlines with hooks to gear specifically developed to capture the particular species. Prior to 1939, dogfish were caught by handlines, setlines; and otter trawls as well as paranzella nets (Harrison and Samson 1942). Vessels using conventional halibut gear entered the fishery in 1939. In British Columbia waters, sunken gillnets were commonly used during the peak fishing years; other gear types there included drift gillnets, longlines, and otter trawls (Barraclough 1953). Drift nets used by Japanese shark fishermen in the western Pacific are described by Kaganovskaya (1937).

Catches

Catches in principal regions of the Atlantic and Pacific Oceans during 1915-61 are reviewed by Jensen (1966). The catches from California, Oregon, Washington, British Columbia, and Alaska in 1937-59 were compared by Alverson and Stansby (1963), and we have combined these with other data to up-date the information (Table 111.4.4).

Table 111.4.4 .--Catch of dogfish in thousands of pounds.[1] [2]

Year	California	Oregon[3]	Washington[3]	British Columbia[4]	Alaska[5]	Total
1937	913	--	1,620	11,322	--	13,855
1938	--	--	578	15,969	--	16,547
1939	--	--	2,365	11,482	--	13,847
1940	--	1,244	3,347	14,488	13	19,092
1941	--	5,084	23,980	25,513	531	55,108
1942	--	1,313	17,374	31,103	40	49,830
1943	--[6]	2,299	23,546	37,555	221	63,621
1944	47[6]	4,374	41,018	56,977	31,115	113,531
1945	20	2,220	23,414	42,694	911	69,259
1946	6	3,109	22,132	20,858	1,001	47,106
1947	--	2,824	15,282	28,160	689	47,955
1948	--	4,659	12,504	22,249	446	39,858
1949	--	3,423	10,645	29,253	918	44,239
1950	--	703	1,928	4,041	15	6,687
1951	--	152	2,452	7,311	10	9,925
1952	--	47	3,065	5,573	..	8,685
1953	--	37	2,405	5,698	--	8,140
1954	--	39	2,012	4,635	--	6,686
1955	--	--	1,935	4,789	--	6,724
1956	--	57	1,526	2,053	--	3,636
1957	--	24	1,861	4,517	--	6,402
1958	--	65	4,233	2,933	--	7,231
1959	--	64	3,092	10,362	--	13,518
1960	--	47	1,378	--	--	1,425
1961	--	50	791	--	--	841
1962	--	10	7 6 3	--	--	773
1963	--	..	867	--	--	867
1964	--	..	1,837	--	--	1,837
1965	--	8	2,075	--	--	2,083
1966	--	--	1,672	903	--	2,575
1967	--	--	1,253	978	--	2,231
1968	--	36	686	623	--	1,345
1969	--	55	600	7/	--	655
1970	--	17	479	305	--	801
1971	--	4	122	283	--	409
1972	--	7/	43	312[8]	--	355
1973	--	1	13	11,555[8]	--	11,569
1974	9/	9/	9/	2,544	--	2,544
1975	9/	9/	9/	1,579	--	1,579

[1] Data for 1937-59 adopted from Alverson and Stansby (1963, Table 1).
[2] The livers only were landed from a large portion of the catch from 1937-59. Because of the varied methods which have been used in computing whole weights and reported landings, the values shown are estimates only for those years.
[3] 1937-67 data from U.S. Fish and Wildlife Service, Stat. Dig. nos.1,4, 7, 11, 14, 16, 18, 19, 21, 22, 25, 27, 30, 34, 36, 39, 41, 43, 44, 49, 53, 54, 56-61; 1968-73 from Natl. Mar. Fish. Serv., Stat. Dig. No's. 62-67.
[4] 1937-51 from Fishery Statistics of Canada; 1952-59 from Fishery Statistics of British Columbia--Preliminary (1937-59 total pounds of dogfish caught = pounds of livers landed x 8.33); 1'260-75 from British Columbia Catch Statistics (compiled for 1960-68 by Dep. Fish Canada; 1969-70 by Dep. Fish. and For. Canada; 1971-75 by Dep. Environ. Canada).
[5] Alaska Fishery and Fur Seal Industries, 1937-54.
[6] Holland (1957)."
[7] Less than 500 lb. or $500.
[8] Plan for eradication of dogfish introduced.
[9] Data not yet published.

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SUGGESTIONS FOR FUTURE RESEARCH

The spiny dogfish is considered a pest by fishermen who resent abrasion of lines, weighting of gear, catches of dogfish instead of target species, and the resultant damage and loss of gear and fishing time. The logical means to solve the problem is to reduce the population of dogfish, but past attempts at such programs have been short-lived.

Future research should be directed toward studying the ecological relation-ships of dogfish to other species, developing markets and products to use the dogfish, and determining the available stocks and optimum sustained yields. Because the spiny dogfish is a slow grower and the young are produced only every two years, management of populations would take careful study to assure that they were not fished to a rate faster than they were recruited (Holden 1974).

Little is known about the populations and abundance of the dogfish in the Gulf of Alaska and eastern Bering Sea, but future research probably will depend upon the economic demand for exploitation of the species.

AMERICAN SHAD (Alosa sapidissima)
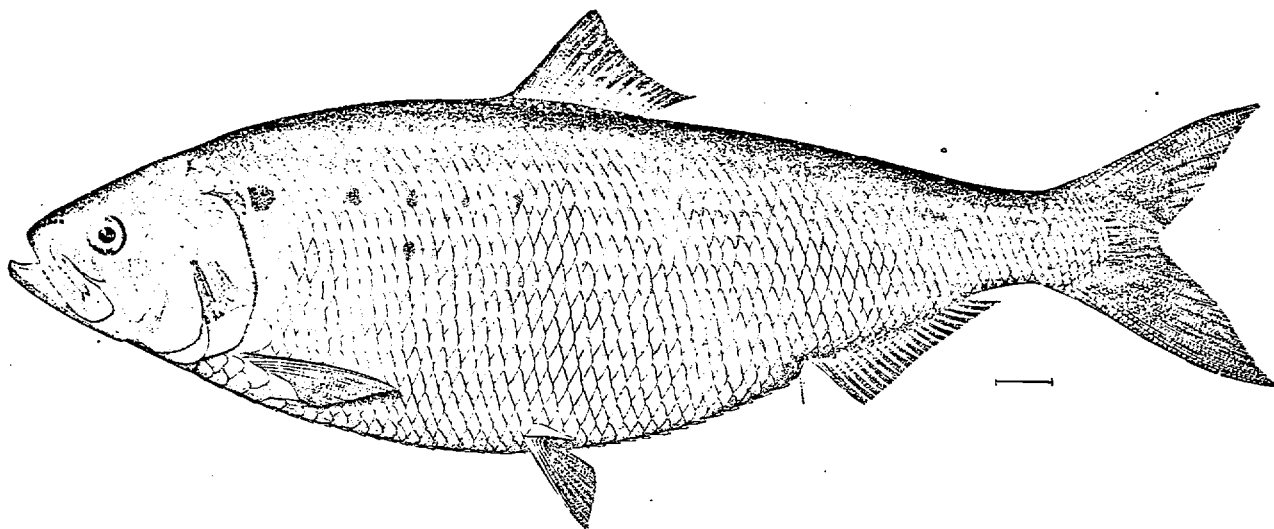
Figure III.5:1.—American shad, Alosa sapidissima (from Smith 1896).

IDENTIFICATION

Alosa sapidissima is the accepted scientific name of this anadromous species
of the family Clupeidae. It is commonly called the American shad, white
shad, or simply shad. Very commonly it is named for the geographic area
where it is caught, thus such names as Atlantic shad, Potomac River shad,
Susquehanna River shad, Delaware shad, and Columbia River shad are seen
in the literature (Scott and. Crossman 1973). Although it was introduced
to the Pacific Coast and spread north and south , no evidence of development
of subspecies has been found anywhere throughout its distribution.

DISTRIBUTION

The shad is an anadromous member of the herring family originally found.
on the east coast of the United States and Canada from Florida to New-
foundland. It was introduced to the Sacramento River in California in
1871, and it was reported in 1876 or 1877 in the Columbia River, in Puget
Sound in 1882, and the Fraser River in Canada and the Stikine River in
Alaska in 1891 (Welander 1940). It continued to spread through the Gulf
of Alaska, and it has been reported in Korfa Bay and Uala Cove on the
eastern side of Kamchatka (Svetovidov 1952). Its southern limit on the
Pacific coast is Todos Santos Bay, Baja California (Hart 1973).

Fig. 111.5.2 shows the years shad appeared in various river systems at
the North American Pacific Coast (Welander 1940).. Virtually nothing is
known of the distribution of the shad within rivers of the Pacific Coast.

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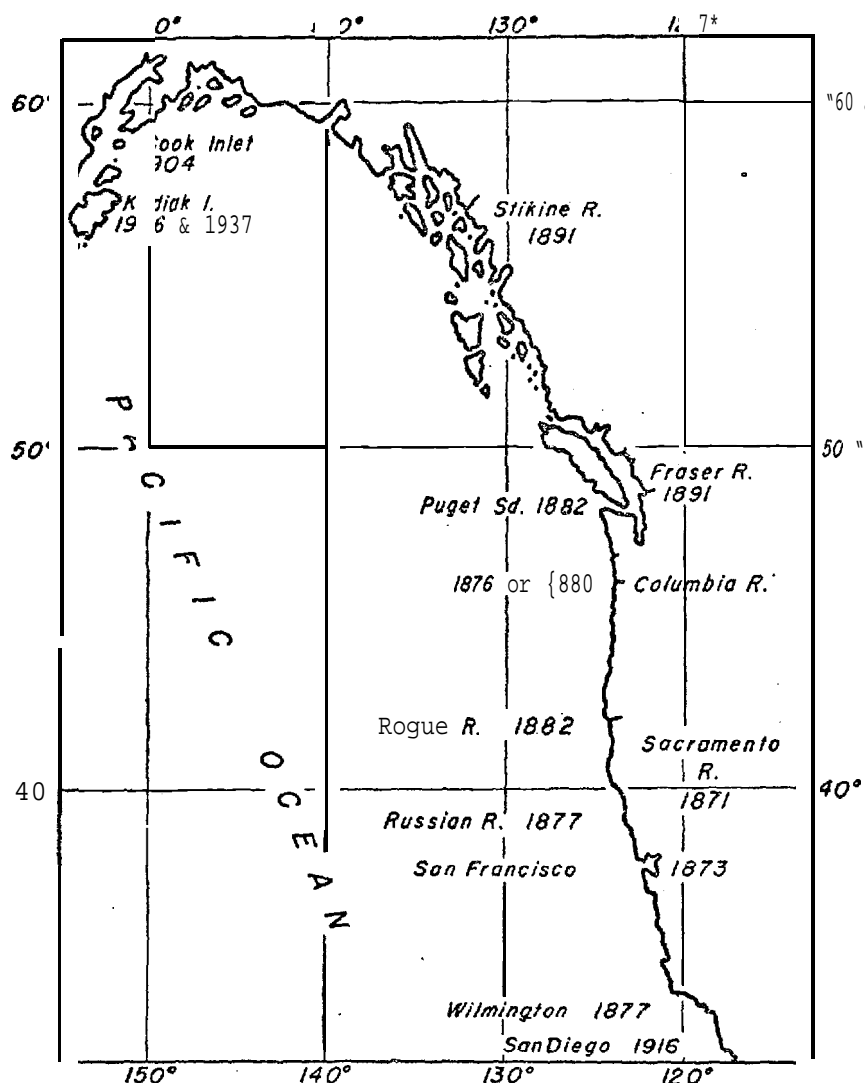
Figure 111.5.2.--Distribution of shad along the northwest coast
of North America with dates of their first appearances at the
various localities (from Welander 1940).

On the eastern seaboard of the United States and Canada, the shad has
been of varying but substantial economic importance. The species has been
studied intensively at various times and a great deal of information and
data have been published. Most of the information does not apply specifically
to the shad of the Pacific Coast, however, and especially to the Gulf
of Alaska and Bering Sea areas of interest to this report. Because of
this, and because so little is known about the species in the Pacific,
most of the material in this report will be synoptic in form and taken
from publications on the shad in the Atlantic Ocean.

LIFE HISTORY

There are some differences in the life history between shad on the east
coast as compared to the west coast of the United States. Most of what
follows was taken from publications concerning shad on the east coast,
but specific differences, when known, will be pointed out,

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Reproduction

According to **Scott and Crossman** (1973) , shad ascend rivers in the spring
to spawn, the time depending to some degree on water temperature. In Canada
this migration comes in May and June and sometimes extends into July.
The fish mature at a length of 46 to 48 cm and after age of 4 or 5 years
(Hart 1973). The adults do not feed during their upstream migration on
either the Atlantic or Pacific Coast (Smith 1896, Leim 1924). On the **east**
coast shad migrate only a relatively short distance above tidal waters
to start **spawning** in freshwater when the temperature is **12°C.** On the west
coast, at least in the Sacramento-San **Joaquin** river delta area, spawning
may occur in brackish water (Stevens 1966). However, Browning (1974) reported
that Columbia River shad spawn in many tributaries as far upstream as
the Snake River, far above brackish water and tidal "influences. On both
the east and west **coasts,** the peak of spawning occurs when the temperature
is **18.5°C (Leggett** and Whitney 1972). On the Columbia River, **90%** of the
upstream migrants pass Bonneville Dam when the temperatures are **16-19.5°C.**

Leim (1924) stated that spawning occurs in the evening after sundown **until**
midnight or later. Each female, depending on size, may carry from 20,000
to a maximum of 616,000 eggs (average is 25,000-30,000). The eggs are
fertilized in moving water, sometimes with several males being involved
with each female. If the water velocity is low enough, the **demersal** eggs
settle immediately to the bottom. Fertilized eggs are 2.5 to 3.5 mm in
diameter (Scott and **Crossman** 1973). After spawning the adults return to
the sea, some surviving to spawn two or more times.

Growth and **Nutrition**

Growth

Leim **(1924)** found **that hatching** occurs in 12-15 days at 12°C and in 6-8
days at **17°C** under artificial conditions. Svetovidov (1952) said that
hatching is a function of" temperature as indicated by the following:

Temperature **(C)**	Hours to hatch
12.2°	408
13.9°.	148
17.8°	109

Leim also found that the optimum conditions for development of eggs and
larvae were in slightly brackish water with a salinity of 7.5 o/oo at
17 °C .

The larvae are about 9-10 mm long when hatched, and they drift down the
river their first summer (Hart 1973). Growth is rapid according to Leim
(1924). They reach a length of 50-75 mm by autumn when they reach the
sea, and they average 75-175 mm at the end of the first season. **The following**
data from Leim show the growth of Atlantic coast shad:

Age	1	2	3	4	5	6	7
Length (cm)	12.9	26.3	35.2	41.9	48.4	51.4	52.5

Scott and Crossman (1973), reviewing the literature, noted that shad were sexually mature at age 4 but most are 5 years old and 46-48 cm long at maturity. The oldest shad were 11 years.

Food and feeding

The shad are classified as plankton feeders , with the young in fresh water eating copepods and insect larvae (Leim and Scott 1966, Scott and Grossman 1973). Scott and Crossman also noted that upstream migrating adults ate little if anything. Stevens (1966) made a detailed study of shad food habits in the Sacramento-San Joaquin Delta.

The most prominent food item of 'shad in the sea was copepods, followed by mysids, ostracods, and other planktonic crustaceans (Leim 1924). Other food included molluscs, vegetable matter and occasional small fish or fish larvae.

Predators and Competitors

Shad were found in stomachs of fur seals, Callorhinus ursinus, examined n the eastern North Pacific Ocean in 1958-62. 1964, and 1967 (North Pacific Fur Seal Commission 1962, 1969, 1975). In 1958-61, they were found in stomachs off the coast of California (lat 36-38°N and 41-42°N), off Oregon (lat 44-45°N), and off Washington (lat 46-49°N) in MarcI-May. The percentage of occurrence related to other food items in stomachs ranged from 3.3% (7 seals) off British Columbia in spring 1959 to 24.2% (15 seals) off Washington in winter 1967. An adult female harbor porpoise, Phocaena phocaena, was found choked on a 375 mm shad in Gray's Harbor, Washington (Scheffer and Slipp 1948).

In fresh water, young shad are eaten by a wide variety of fish.

Literature about competitors to the shad is scanty. In San Francisco Bay and tributaries they were found associated with salmon, herring, anchovies, smelt , and striped bass and were caught with gear used to take those species (Smith 1896). Smith also noted that they were caught in pound nets with salmon, sturgeon, and other fish on the Columbia River.

Parasites

Leim (1924) found three internal parasites in shad: Ascaris adunca, Echinorhynchus acus and Contracaecum, a nematode. The only reported external parasites were copepods. Caligus rapax and Lernallnicus radiatus. Hoffman (1967, cited by Scott and Crossman 1973) extended the list to include the trematode, Clinostomum marginatum, and the crustacean, Argulus canadensis.

Physiology

Tagatz (1961), working on the east coast, found adults and juveniles were tolerant to some transfers between salt and fresh water at most of the temperatures (7.2-26.7°C) used during experiments. However, some of the adults were adversely affected at the higher temperatures when transferred from salt water to fresh water. Juvenile shad survived changes from salt water to fresh water but were not tolerant to abrupt changes from fresh water to salt water within the ranges of temperatures and salinities tested.

Chittenden (1972) found that young shad could endure rapid decreases in
temperature but when given a choice would seek areas where there were
slow decreases in temperature. The cold induced sluggishness, cessation
of feeding, equilibrium losses, wobbly swimming, and collisions with objects
shortly before death. Prolonged exposure to temperatures of 4-6°C caused
death unless the fish had been acclimated. Temperature does control, to
some degree, the time of entering fresh water. It also may affect gonad
development , inhibit upstream migration, and ultimately may adversely
effect spawning and survival of eggs.

Evidence has been found that highly excited young shad may die sooner
than those that are less excited, thus handling and transferring can result
in high mortalities (Chittenden 1973).

Behavior

On the west coast, shad are usually caught as single fish mixed in with
other species; in bottom trawling in coastal -waters for example. No evidence
has been found that they school in coastal waters as do herring or anchovies.

Leggett and Whitney (1972) traced the history of the east coast shad fisheries
and the extensive tagging work that has been done there through the years.
The information, when summed, indicated that there is an annual clockwise
migration of shad in the Atlantic Ocean off the coast. In the summer (July,
August, and September) the shad apparently migrate to the Gulf of Maine,
staying between the 13° and 18° isotherms. As winter comes on they move
to the middle Atlantic waters, then move on south in the spring while
staying in the 13-18*C temperature range.

On the basis of the data from the east coast, Leggett and Whitney hypothesized
that there is a similar type migration path in the Pacific Ocean as shown
by the time sequence and the location of the 13°-18°C isotherm arenas shown
in Fig. 111.5.3.

It is evident from Figure 111.5.3 that at one time or another during the
year, shad could be found from Baja California to various parts of the
coast of Alaska. Indeed information on the distribution of shad in the
Pacific, "based on observed presence as reported above, supports the hypothesis.

POPULATION STRUCTURE AND DYNAMICS

The review of shad fisheries of North America by Mansueti and Kolb (1953)
and Leim's (1924) work on life history and abundance, are the most thorough
available. They include information on fluctuations in catches, size and
age composition of catches, factors causing decline of shad production,
and discussions of management of the populations. These and other literature
sources discuss only the populations of the Atlantic Ocean, however.

If anything has been published on population structure and dynamics of
shad of the west coast of the United States, except for catch statistics,
we did not find it. We found nothing about distribution or abundance of
shad in the Gulf of Alaska or the eastern Bering Sea except for scattered
distribution records.
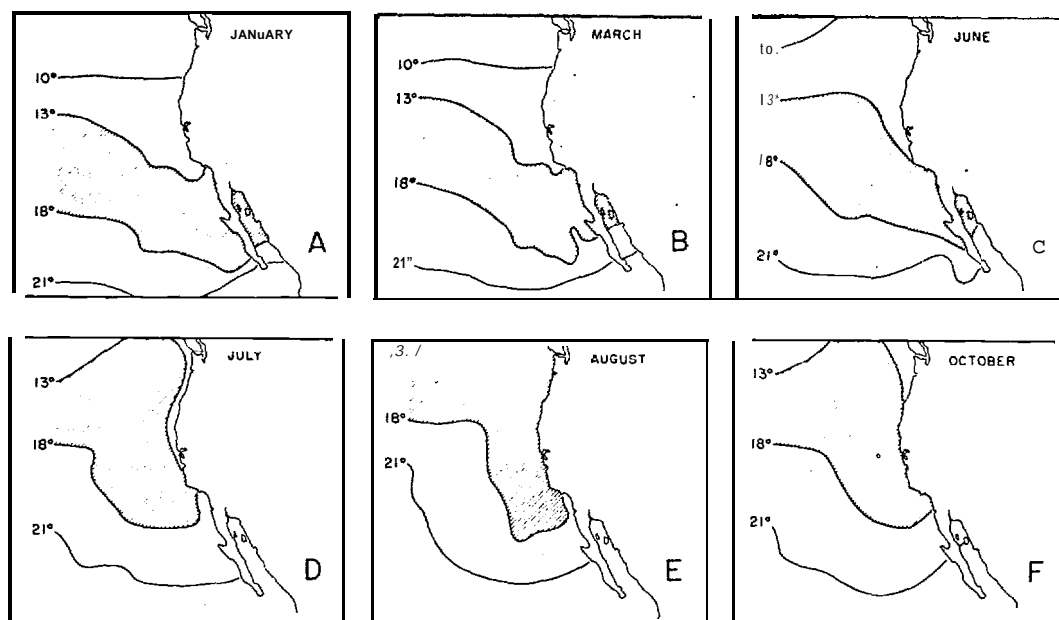
Figure 111.5.3.--Pacific Ocean average sea-surface temperatures and
predicted shad distributions for selected months. (Temperature
charts. adapted from U.S. Navy Hydrographic Office 1954.) (From
Leggett and Whitney 1972).

FISHING

The history of American shad fisheries in North America to about 1950
was reviewed by Mansueti and Kolb (1953). The fishery has been of commercial
importance on the Atlantic coast since the early 1800's, and the Pacific
coast fishery began within a few years after the fish was introduced into
the Sacramento River in 1871. Landings have varied substantially year
to year and from decade to decade.

At one time or another fisheries on the Pacific Coast have existed in
the San Joaquin and Sacramento Rivers and in coastal waters of California;
in coastal rivers and waters of Oregon; in the Columbia River, common
to both Oregon and Washington; in coastal waters, Grays Harbor, and Puget
Sound, Washington; and in the Fraser River, British Columbia.

A review of statistics by Mansueti and Kolb (1953) shows that a total
of 738,000 pounds was caught in the three western Pacific states in 1892,
and a peak of 7,478,000 pounds (of which nearly 7,000,000 pounds were
from California) was taken in 1915. The Pacific Marine Fisheries Commission
(1948) listed the shad fisheries of the three states as producing more
than 3,000,000 pounds of fish per year in the 1940's. The river fishery
in California. largest for shad on the west coast for many years, was
halted fter 1957 and no attempt was made to fish in the open sea after
that.⁻ In recent years the bulk of the catches have been in Oregon, pre-
dominantly from the Columbia River. The average annual catch in Washington

1/ Ahlstrom, Elbert H. [n.d.] Our changing fisheries--California region.
   Bur. Commer. Fish., Fish.-Oceanogr. Center, La Jolla, Calif., unpubl.
   manuscr.

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and Oregon in 1970-73 'was nearly 604,000 pounds of which 566,000 pounds
were caught in Oregon and 38,000 pounds in Washington (National Marine
Fisheries Service 1973-76). The average annual landings in British Columbia
in 1971-73 were 44,000 pounds.

Mansueti and Kolb (1953) reported they found no mention in the literature
to the use of shad as food fish in Alaska, but their opinion was that
shad populations might possibly be dispersing northward and eventually
might. become valuable in Alaska.

Much of the shad landings have been as incidental catches to salmon or
other fisheries. The flesh of shad is bony, so the fish has been taken
in recent years mostly for the roe, for reduction, ·and for pet foods.[2]/

Shad have been caught by a variety of gears including traps, seines, fish
wheels, gillnets, dip nets, pound nets, and otter trawls according to
Mansueti and Kolb. In addition, sports fishing for shad as a game fish
has increased.

SUGGESTIONS FOR FUTURE RESEARCH

The shad is a creature of inshore and fresh waters. Future research may
pinpoint its distribution and abundance in. the easterⁿ Pacific Ocean more
accurately. If it is present in any quantities in southeast Alaska or
inshore areas of the Gulf of Alaska, experimental fishing with appropriate
gear in logical areas and appropriate times would be necessary to determine
its availability for potential fisheries.

2_/ Young, F. 1970. Biology Columbia River shad and the development of
    selective commercial fishing gear. Fish. Comm. Oreg., Res. Div., Prog.
    Rep., Jan. 1969–Sept. 1970. 12 p. Typescript.

PACIFIC HERRING (Clupea harengus pallasi)
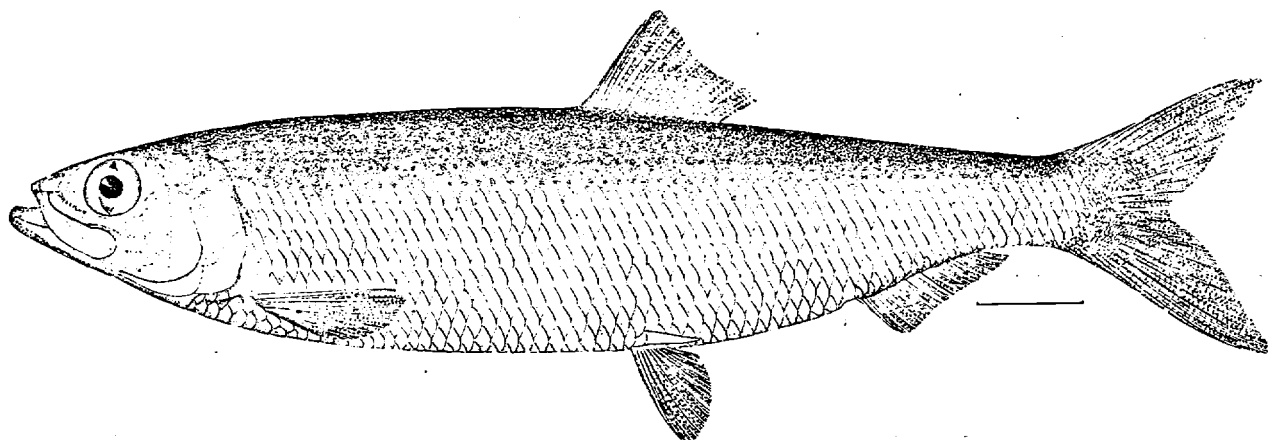
Figure 111.6.1.--Pacific herring, Clupea harengus pallasi (after Turner 1886).

IDENTIFICATION

The Pacific herring (Clupea harengus pallasi Valenciennes) belongs to the family
Clupeidae. It was first described by the Russian scientist Petr Simon Pallas
from the Kamchatka River in 1811. According to Fedorov(1973a), the Pacific
herring is by origin an Atlantic form, and it penetrated into the Pacific Ocean
along the coast of Asia in the Post-glacial Recession. Although the Pacific
herring has, on the average, a lesser number of vertebrae than the Atlantic
herring (Clupea harengus harengus), the two are regarded not as species but
as subspecies of Clupea harengus (Svetovidov 1952).

In external appearance (Fig. 111.6.1) it is very similar to the Atlantic herring,
being generally blue-green to olive in color on the dorsal surface, shading
to silvery on the sides and belly, and bearing large cycloid scales (Hart 1973).
In the eastern Pacific it grows to 13 inches (33 cm) in length, but averages
9-10 inches (22-25 cm) and weighs about one-third pound (150 g) (Reid 1972,
Hart 1973). In Asiatic waters it is said to grow as large as nearly 20 inches
(50 cm) but averages 8 inches (24 cm) (Svetovidov 1952). The average number
of vertebrae on the North American shores increases from south to north --
from 50.68 (San Diego) to 53.22 (Unalaska) according the Svetovidov.

The common name of the Pacific herring in Japan is nishin or Taiheiyo nishin
(Okada and Kobayashi 1968), it is Tikhookeanskaya sel'd or Vostochnaya sel'd
in the U.S.S.R. (Svetovidov 1952), is I⌣káth loo u̇'k pŭk in the Eskimo lan-
guage and has the Aleutian name of U'l ngan (Turner 1886).

DISTRIBUTION

The Pacific herring is found in the northern part of the Pacific Ocean from
southern California north to Cape Bathurst in the Beaufort Sea, across to
the Lena River in the Arctic Ocean, south to Kamchatka, the Okhotsk Sea,
and as far as Korea (Hart 1973).

There are many localized **populations** throughout the distribution range with
varying degrees of homing instinct (**Kasahara** 1961), depending upon whether
they spawn in brackish lakes or lagoons or on the open sea coast. **Alderdice**
and **Velsen** (1971) believe that Pacific herring populations on the North
American coast are confined to regions with protected spawning-waters of
reduced salinity (8-28 o/oo) at temperatures between **5.0-5.5°C** and **8.8·or
9°C,** and that the size of these populations is related to the physical extent
of the regions that provide these requirements. Herring concentrations are
densest on narrow continental shelf areas to a maximum depth of about 200 m.

Distribution in the Eastern Bering Sea

The distribution and abundance of Pacific herring populations in the eastern
Bering Sea fluctuates from year to year and area to area. In some instances, .
herring may be plentiful enough to support a fishery one year and be nearly
absent the next year in the same area. These fluctuations are caused by
a number of natural and fishery-related factors.

Early explorers and scientists noted a few places where herring were fished
in coastal areas in the Bering Sea by native populations. A.Small commercial
fishery developed in Norton Sound beginning in 1909, and another fishery
developed at **Unalaska** in the Aleutian Islands in 1928 and lasted until 1945.
Little was known about offshore distributions despite these commercial opera-
tions.

The first extensive data about offshore distributions came from exploratory
investigations by Soviet research and fishing vessels in 1957-64. The Soviet
research, plus knowledge obtained from commercial herring fisheries they
began in 1961, furnish most of the available information about herring distri-
bution in the eastern Bering Sea.

Herring research in 1959-61 resulted in a general concept **by Dudnik** and
Usol'tsev (1964) of herring distribution in the eastern Bering **Sea (Fig.III.**
6.2), particularly the winter concentrations. Based on analysis of work
done in 1960-63, **Prokhorov** (1968) defined eastern and western wintering
areas of local populations, the **Pribilof** and the **Karaginskii,** in the Bering
Sea. Shaboneev (1965) carried out experimental fishing from three vessels
in winter-spring, autumn-winter, and winter periods of 1961-63 to further
analyze the winter distribution. In 1964 the Soviets sent four exploratory
vessels to the eastern Bering Sea (Fig. 111.6.3) in order to obtain a more
accurate idea of the summer distribution (**Rumyantsev** and Darda 1970).

According to Soviet research, the wintering area for herring from December
to March is northwest of the **Pribilof** Islands between **lat** 58 and 59°N at
depths of 105-137 m in an area of 500-900 square miles. In 1961, the concen-
trations by spring covered 1,100 square miles (Shaboneev 1965). Wintering
concentrations are fished commercially from late **November** to March. Other
wintering areas possibly exist; data indicate considerable numbers of herring
may be found under the ice fields further north. The concentrations may
shift during periods of severe winters, and examples of this shift are shown
in Figure 111.6.4 which compares the winters of 1961-63.
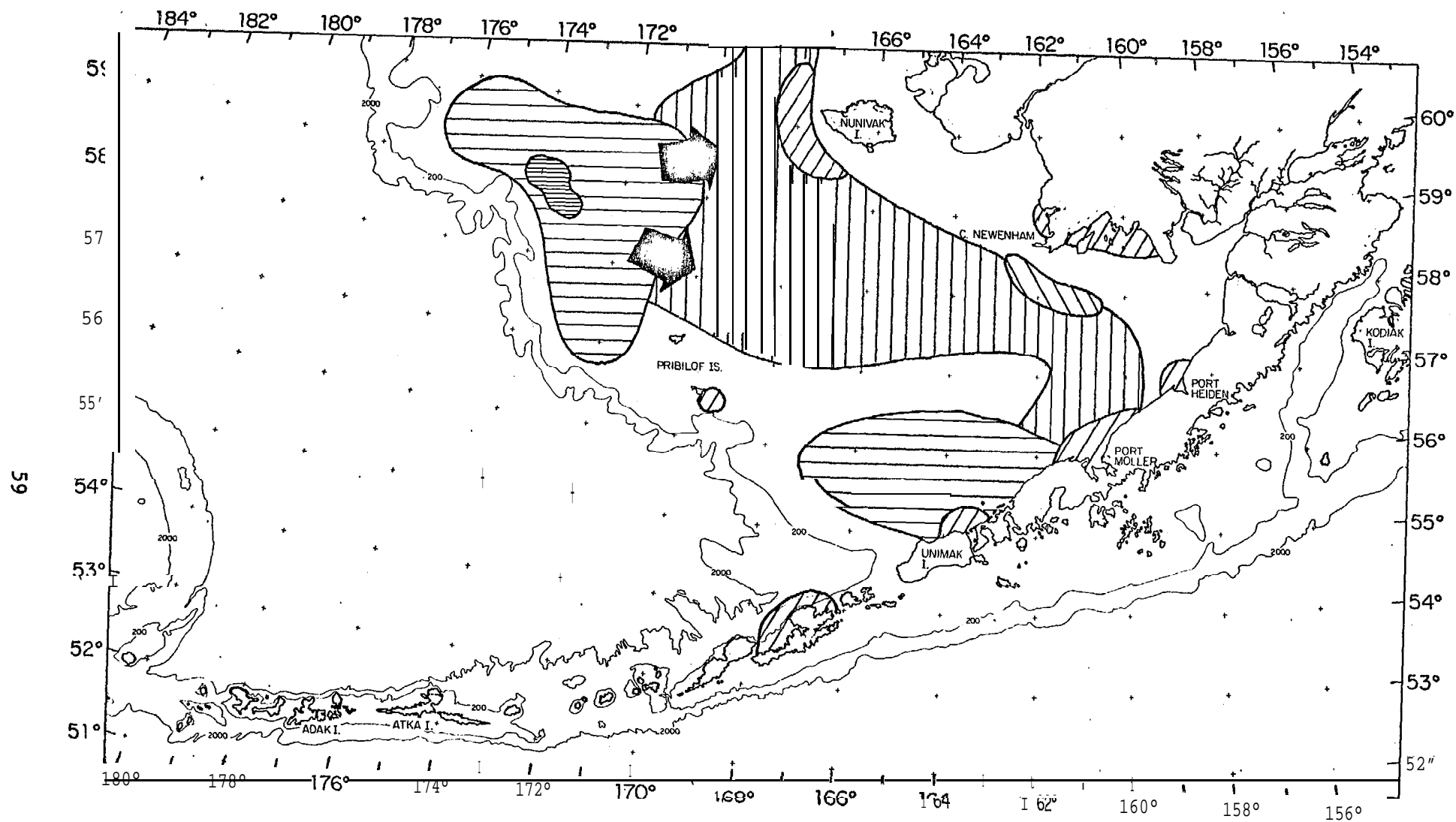
Figure 111.6.2.—Distribution of Pacific herring in the eastern Bering Sea (based on Dudnik and Usol'tsev 1964, Shaboneev 1965, Baxter 2975). ▬▬ winter concentrations, ‖‖‖ distribution in July-August, ▬▬ distribution in September-October, \\\\ area of appearance of herring with ripe sex products, ///// spawning grounds, ◆ probable routes of migration,
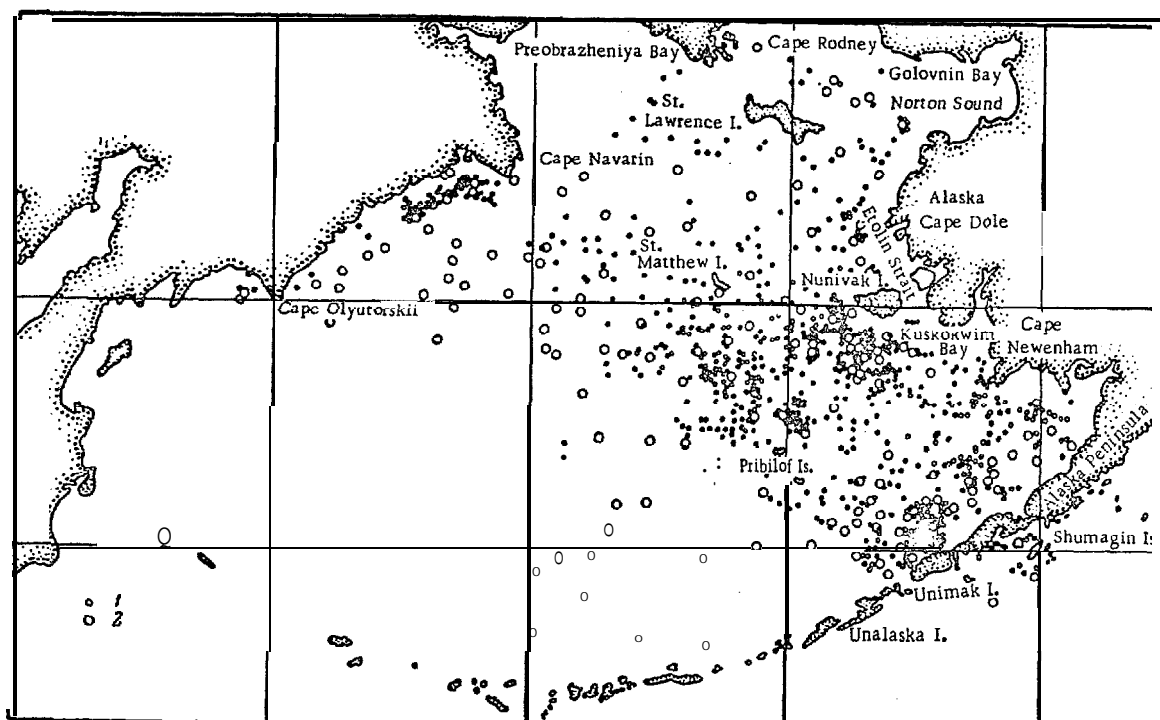
Figure 111.6.3 .--Sampling stations of the Soviet herring reconnaissance
   expedition, 1964: 1-trawls; 2-drift nets (from Rumyantsev and Darda
   1970) .

The Soviet studies in 1964 indicated that concentrations began to form
in October-November, and the dense schools stayed mainly about 5-10 m above
the bottom by day at depths of 105-137 m and water temperatures of 2-3.5°C.
During this period, the herring had distinct diurnal migrations. Tempera-
tures were lower, 0.9-2°C, at the end of wintering in the latter part of
March. Much of the wintering area is covered by ice in February and March
and the herring move southeast to warmer waters in severe winters.

At the end of March and in April 1964, herring left the wintering grounds
and migrated northeast and southeast. 'By mid-April and in May, concentrations
were southwest of Nunivak Island and in the Alaska Peninsula area northwest
of Unimak Island at depths of 10-70 m, demersal .temperatures of 0 to -1.8°C.
The mature herring were found in May at Unimak Island and the northwest
coast of the Alaska Peninsula and in May and the first half of June on the
coast from Cape Newenham to Cape Romanzof (Figs. III.6.5, III.6.6). They
were not found below 70 m in June but were divided in two groups. One group,
consisting mainly of 2-, 3- and 4-year-olds at stage II of maturity and
immature fish, was at depths of 50-70 m at temperatures of 0 to -1°C; the
other group, found at 30-50 m and temperatures of 3-4°C, consisted of spent
fish.

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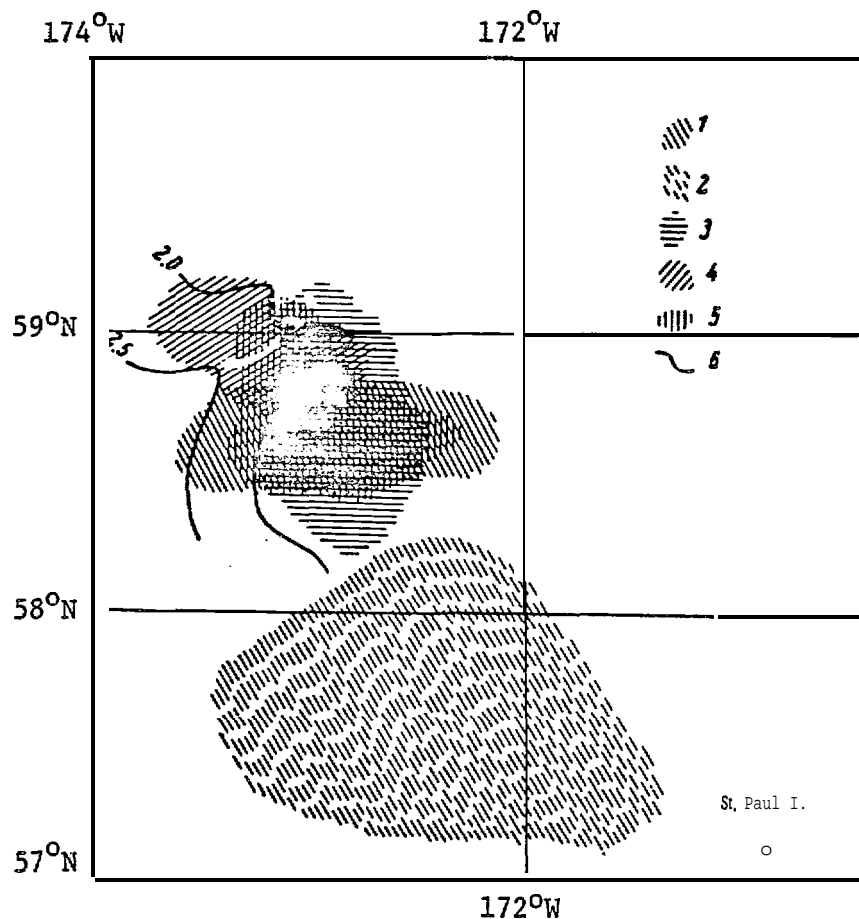
Figure III.6.4.--Distribution of herring in the eastern part of the Bering
   S e a :

   I-February 1961; 2-March 1961; 3-February 1962; 4-February 1963; 5-March
   1963; 6-isotherms in February 1963. (From Shaboneev 1965). Latitude
   and longitude were not given in original but were assumed from textual
   descriptions.

In July, the herring were in surface warmed waters in a narrow coastal zone
including bays of the Alaska coast in water depths of. less than 30 m and
temperatures of 4-6°C. Practically no herring were in the Nunivak and Unimak
islands regions in early July (Fig. 111.6.7). The bulk of the herring in
July apparently stayed in bays and coastal regions of the Alaska coast (Dudnik
and Usol'tsev 1964, Rumyantsev and Darda 1970).

Herring in the eastern part of the Bering Sea began to migrate toward the
slope in August and reappeared in the Nunivak and Unimak Islands areas (Fig.
111.6.8). Two groups again were noted -- one, composed mainly of 7-year-olds,
was located northeast of the Pribilof Islands at depths of 50-70 m and water
temperatures of 2-3°C; the other consisted principally of 4- and 5-year-
olds and was in the Nunivak area at depths of 10-30 m, temperatures of 6-11*C.
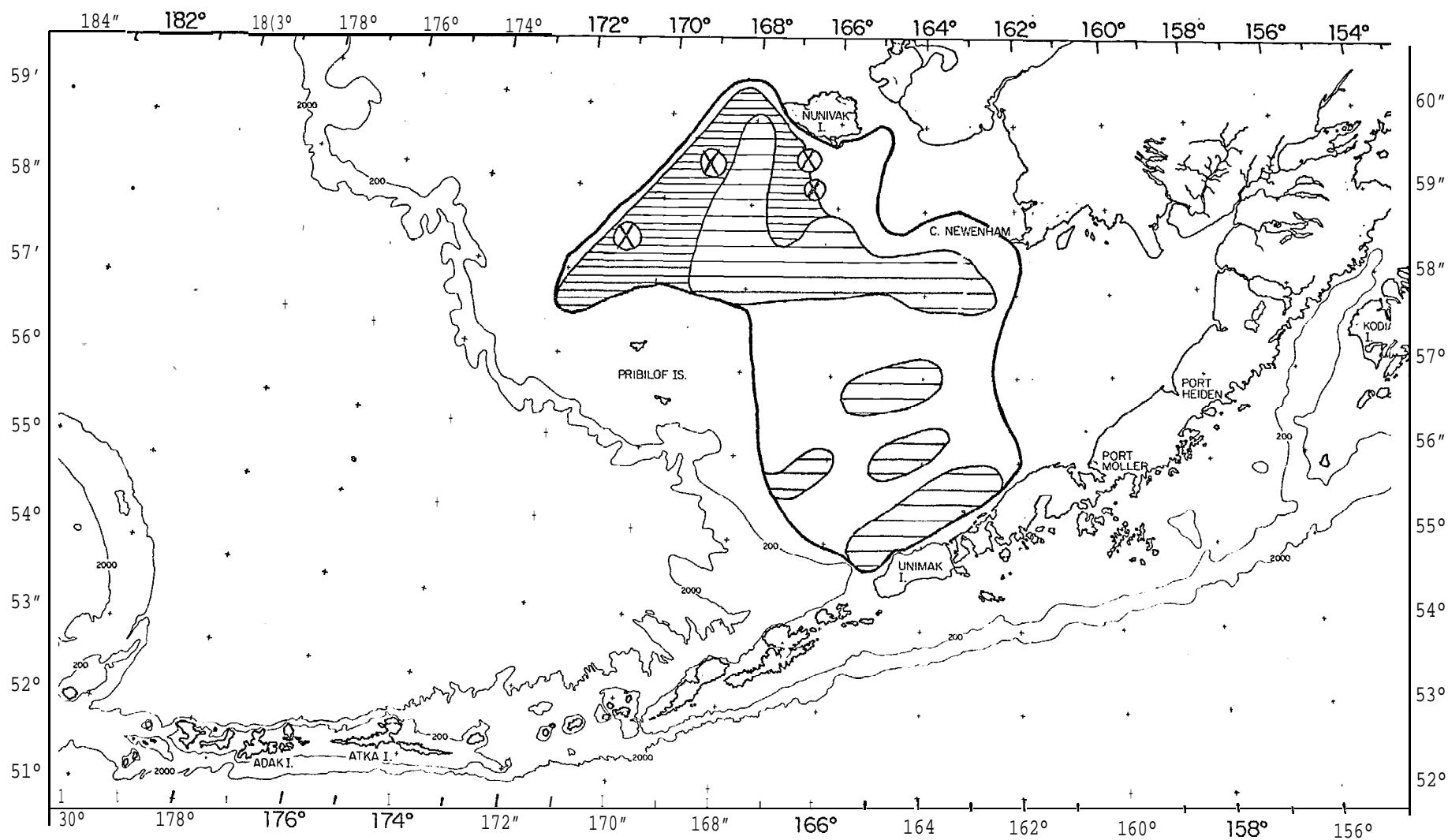
Figure 111.6.5. --Distribution of herring in the eastern Bering Sea, May 1964, based on catch per
30-minute standard trawl and night hauls of 30-50 shackle gillnets of various meshes (modified from
Rumyantsev and Darda 1970). Legend: —area of investigations; — catches of individual fish;
== tens of fish; x - hundreds of fish.
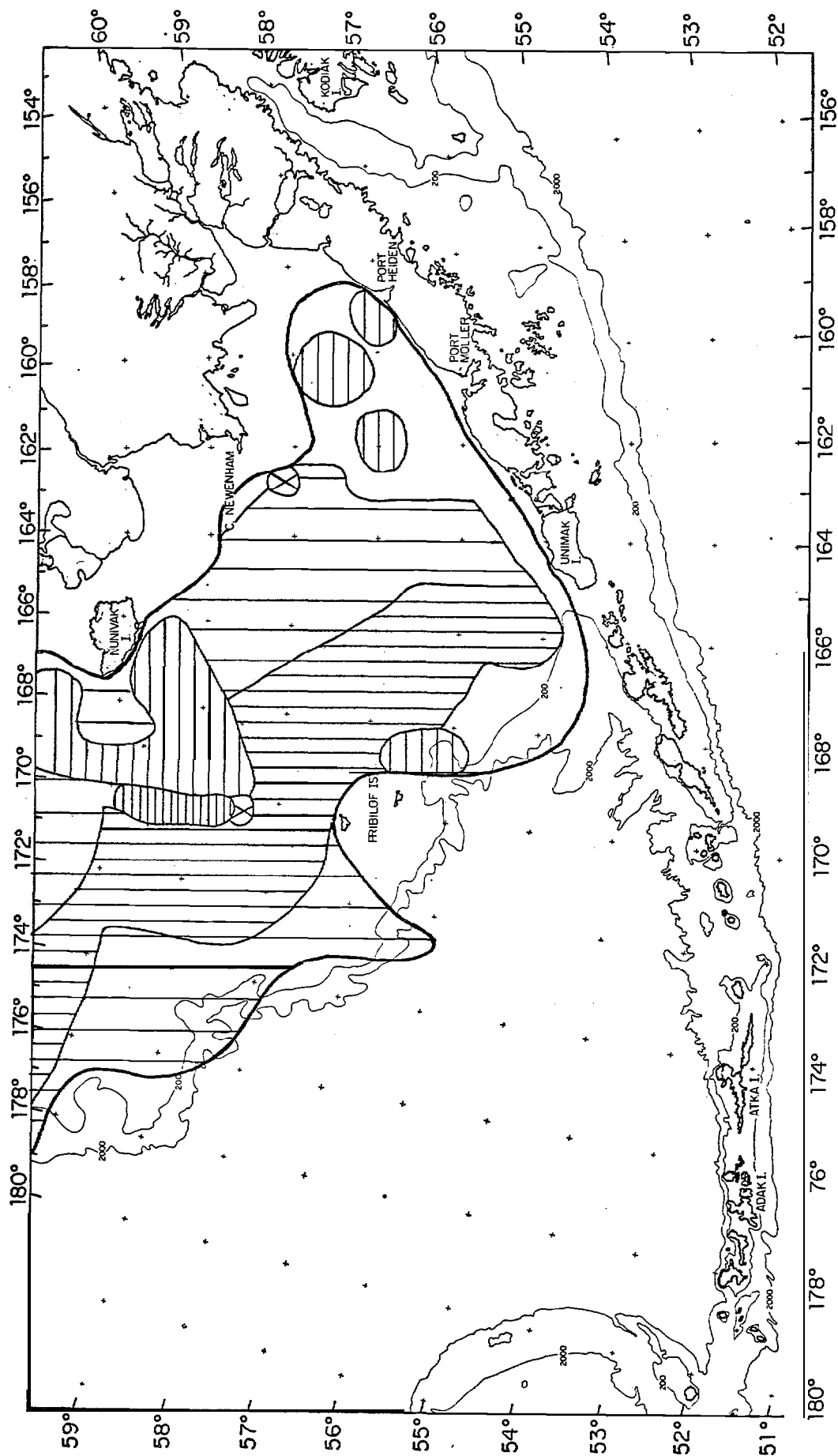
Figure III.6.6.--Distribution of herring in the eastern Bering Sea, June 1964, based on catch per 30-minute standard trawl and night hauls of 30-50 shackle gill nets of various meshes (modified from Rumyantsev and Darda 1970). Legend: —— area of investigations; —— - catches of individual fish; - tens of fish; x - hundreds of fish; |||||- strong "bloom" of phytoplankton;| | | |- weak "bloom" of phytoplankton.
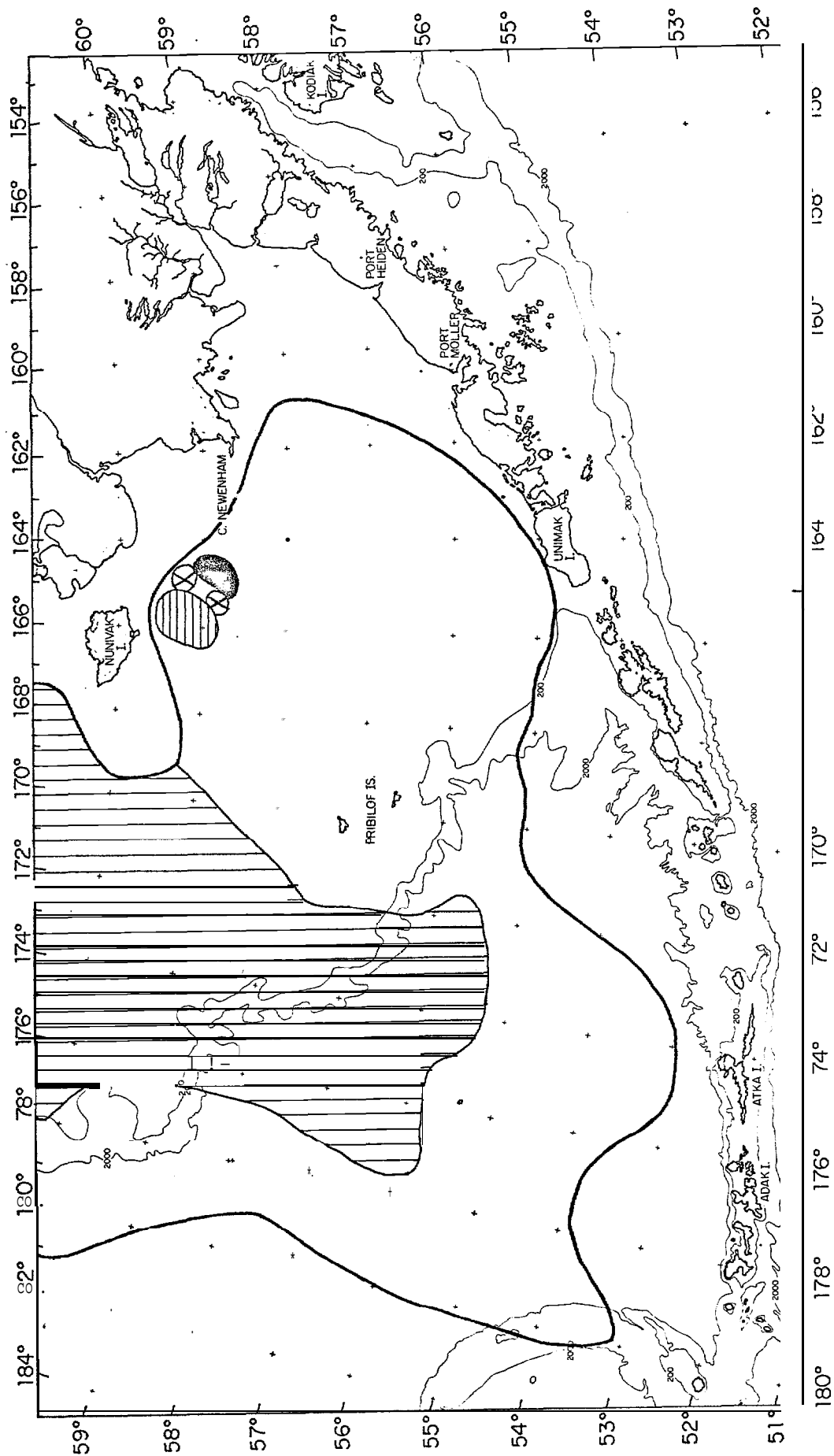
Figure III.6.7.--Distribution of herring in the eastern Bering Sea, July 1964, based on catch per 30-minute standard trawl and night hauls of 30-50 shackle gillnets of various meshes (modified from Rumyantsev and Darda 1970). Legend: ――― area of investigations; ― catches of tens of fish; ||||| strong "bloom" of phytoplankton.

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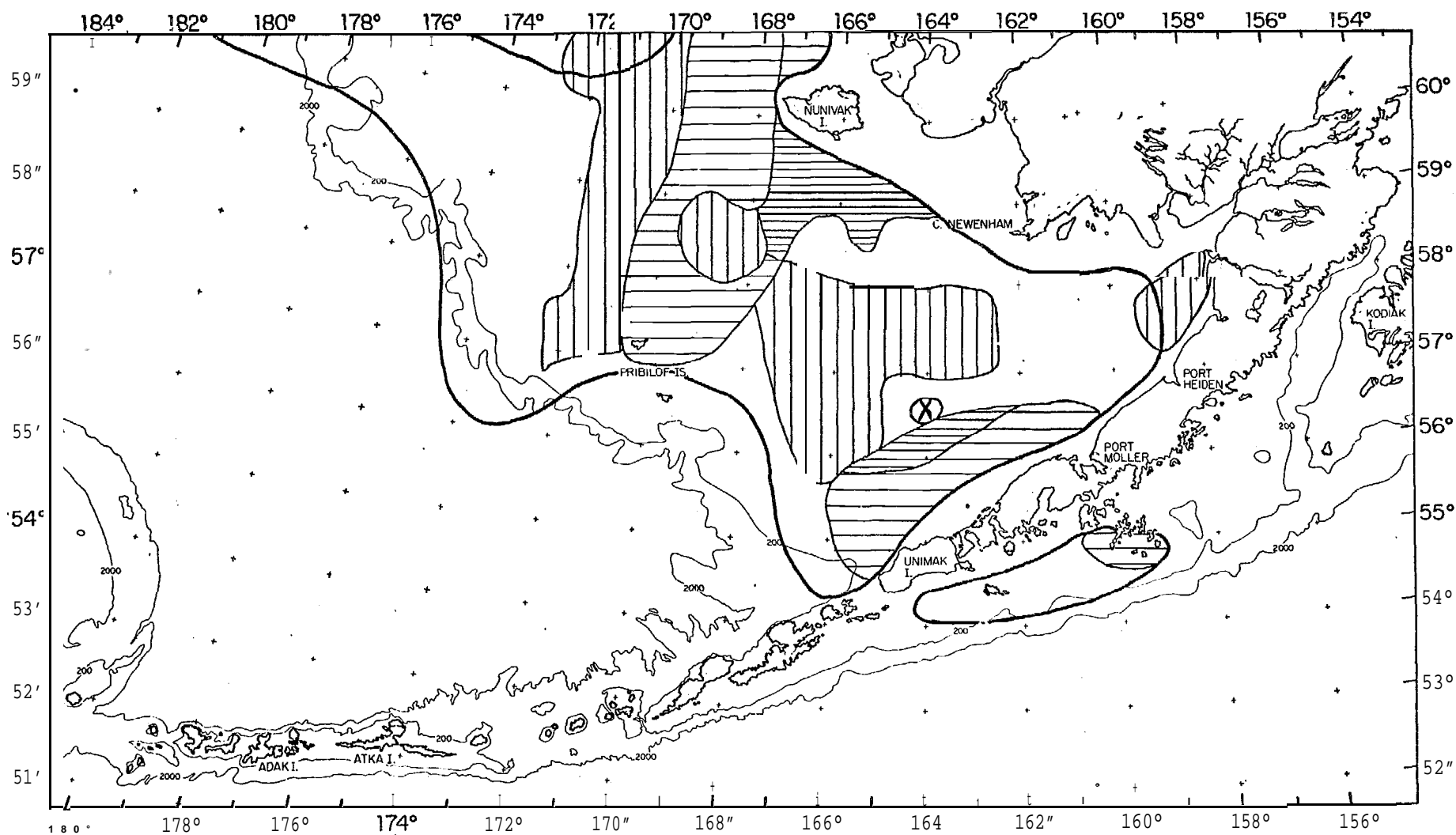
Figure 111.6.8.--Distribution of herring in the eastern Bering Sea, August 1964, based on catch per 30-minute standard trawl and night hauls of 30-50 shackle gillnets of various meshes (modified from Rumyantsev and Darda 1970). Legend: ▬▬▬ area of investigations; ▭▭▭ - catches of individual fish; ▭▭▭ - tens of fish; x - hundreds of fish; ||||| - strong "bloom" of phytoplankton.
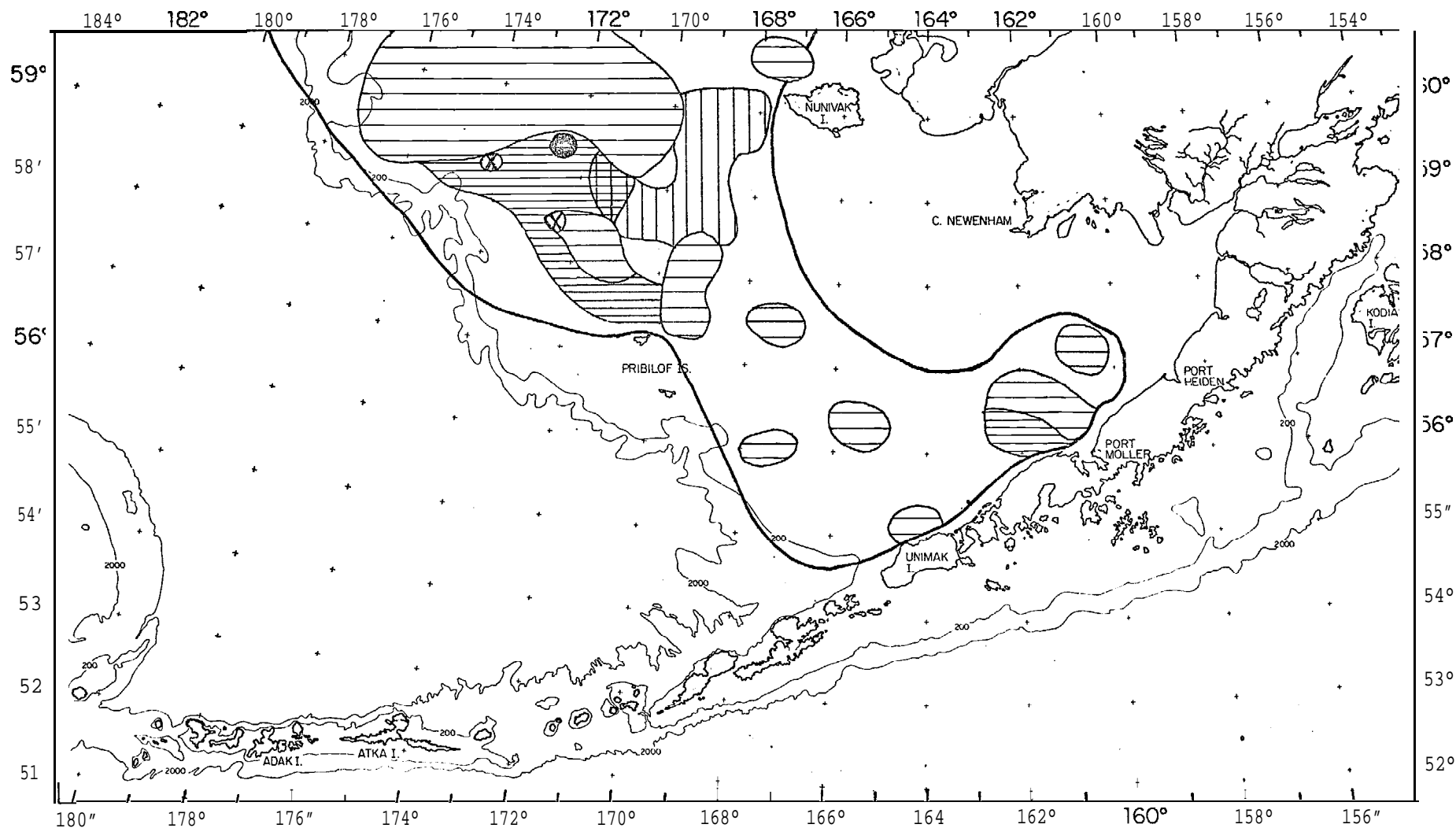
Figure 111.6.9.--Distribution of herring in the eastern Bering Sea, September 1964, based on catch per 30-minute standard trawl and night hauls of 30-50 shackle gillnets of various meshes (modified from Rumyantsev and Darda 1970), Legend: ▬▬▬ area of investigations; ▬▬▬ - catches of individual fish; ═══ tens of fish; x - hundreds of fish; ▓▓▓ - tenths of metric tons (centners);||||| - strong "bloom" of phytoplankton.

The migration away from the coast begun in August continued in September when the fish left Nunivak Island and a new fishing area appeared off St. Matthew Island (Figs. 111.6.9, 111.6.10). The fish were found at 10-125 m and temperatures of -1.5 to 8°C, but most were at 70-90 m and temperatures of 2-3*C.
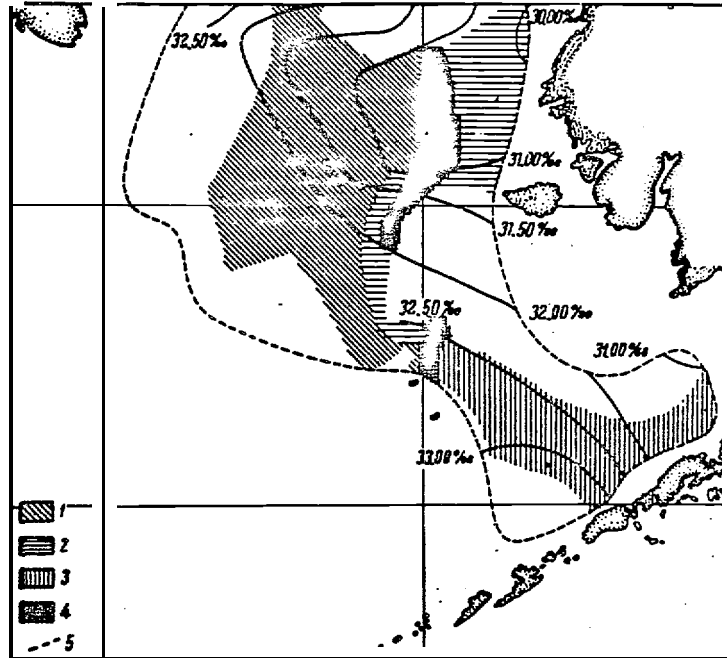
Figure 111.6.10.--Distribution of herring age groups in the eastern Bering Sea, September 1964. 1-herrings older than 5 years (100%); 2-herrings aged 2+ (70-100%); 3-herrings aged 3+ (30-90%); 4-mixed herrings; 5-investigated region (from Rumyantsev and Darda 1970).

The beginning of the concentrations on the wintering grounds northwest of the Pribilof Islands was noted in October 1964 (Figs. III.6.11, III.6.12), mature herrings arriving earlier than the immatures. Herring apparently stopped moving from the east and from northeast of the Unimak Island area but continued coming from north and northwest of the concentration area. Young herring in the St. Matthew Island area had arrived from the Alaskan coast and the Unimak area. Mature herring had inhabited the eastern part of the Bering Sea shelf in summer. The concentrations were at 30-140 m at bottom temperatures of -1 to 7°C, although most were at 50-125 m and temperatures of 2-4°C. In 1962, in comparison, distribution was in the intermediate water mass and partly on the bottom at depths of 115-137 m.

Concentrations on the wintering grounds continued to increase in November 1964 (Fig. 111.6.13) when exploratory vessels found commercial quantities of up to 10 tons per trawl hour. By the end of the month, the fish were found principally in intermediate waters at 90-125 m and temperatures of 2-3*C.
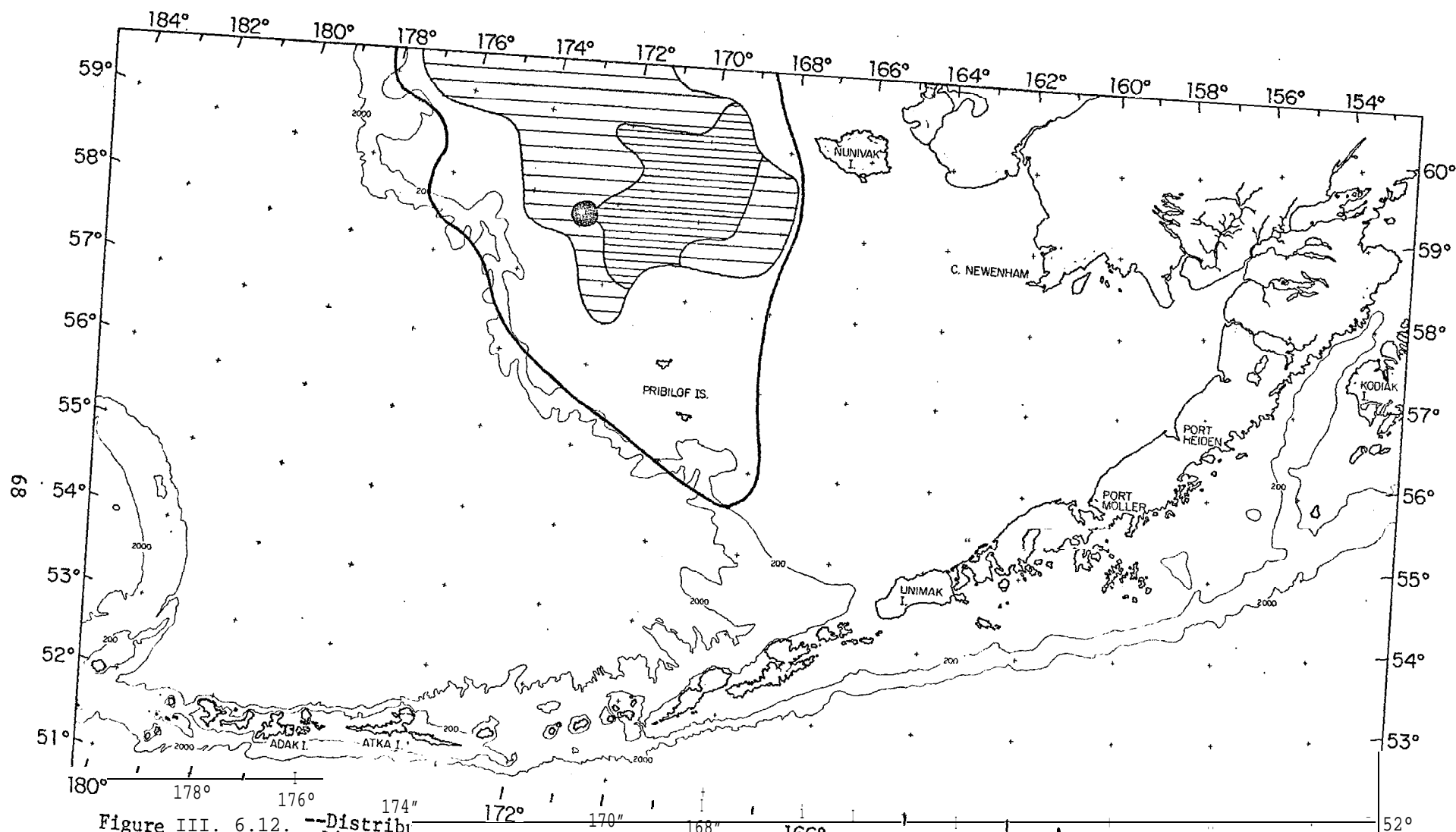
Figure III. 6.12. --Distribution of herring in the eastern Bering sea, October 1964, based on catch per 30-minute standard trawl and night hauls of 30-50 shackle gillnets of various meshes (modified from Rumyantsev and Darda 1972). Legend : ————— area of investigation; ————— catches of individual fish; ————— tens of fish; [shaded box] - tenths of metric tons (centners).
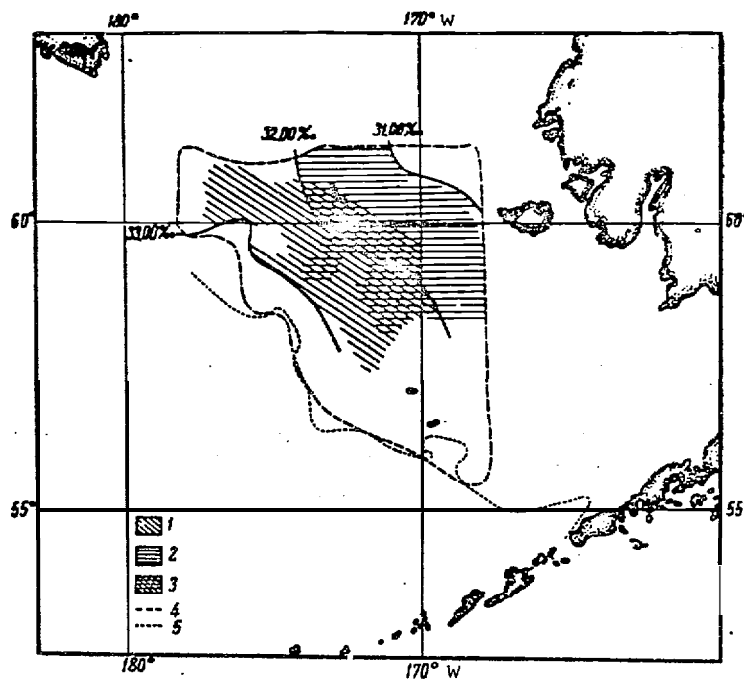
Figure 111.6.12.--Distribution of herring in the eastern Bering Sea in
   October 1964 (from Rumyantsev and Darda 1970). l-mature; 2-immature;
   3-mixed; 4-investigated regions; 5-200 m isobath.
         . . "

The Soviet work in 1964, in summary, indicates that herring in the eastern
Bering Sea winter northwest of the Pribilof Islands and move southeast and
northeast toward the coast in spring. In summer major concentrations are
probably located very close to the coasts in the littoral from Unimak Island
to the Alaska Peninsula and in bays and inlets from Cape Newenham to Cape
Rodney, including Norton Sound. Only small amounts of herring were found
beyond the 20-mile coastal zone in summer (Rumyantsev and Darda 1970). Both
Soviet data and American fishery data show that quantities of herring in
coastal waters are not large. In 1964, at least, relatively permanent populations
were- found in May-=August in the Nunivak Island area and in May, August,
and September in the Unimak Island area. In autumn, the herring returned
from coastal waters to concentrate in the wintering area in the Pribilof
Island region (Rumyantsev and Darda 1970).

Distribution in the Gulf of Alaska

Commercial concentrations of herring in the Gulf of Alaska historically
have been found in three principal areas -- southeastern Alaska, Prince
William Sound, and Kodiak Island. In addition, runs of sufficient abundance
to support small fisheries occasionally have occurred in Cook Inlet (Inter-
national North Pacific Fisheries Commission 1961c), at Chignik on the Alaska
Peninsula (Rounsefell 1930a), and at Yakutat (Cobb 1906; Moberly 1973, 1974b).
Herring also were abundant enough in the Shumagin Islands area to support
a small fishery according to Rounsefell (1930a) and were sampled more recently
by Rumyantsev and Darda (1970) in August 1964 in that area (Fig. 111.6.8).

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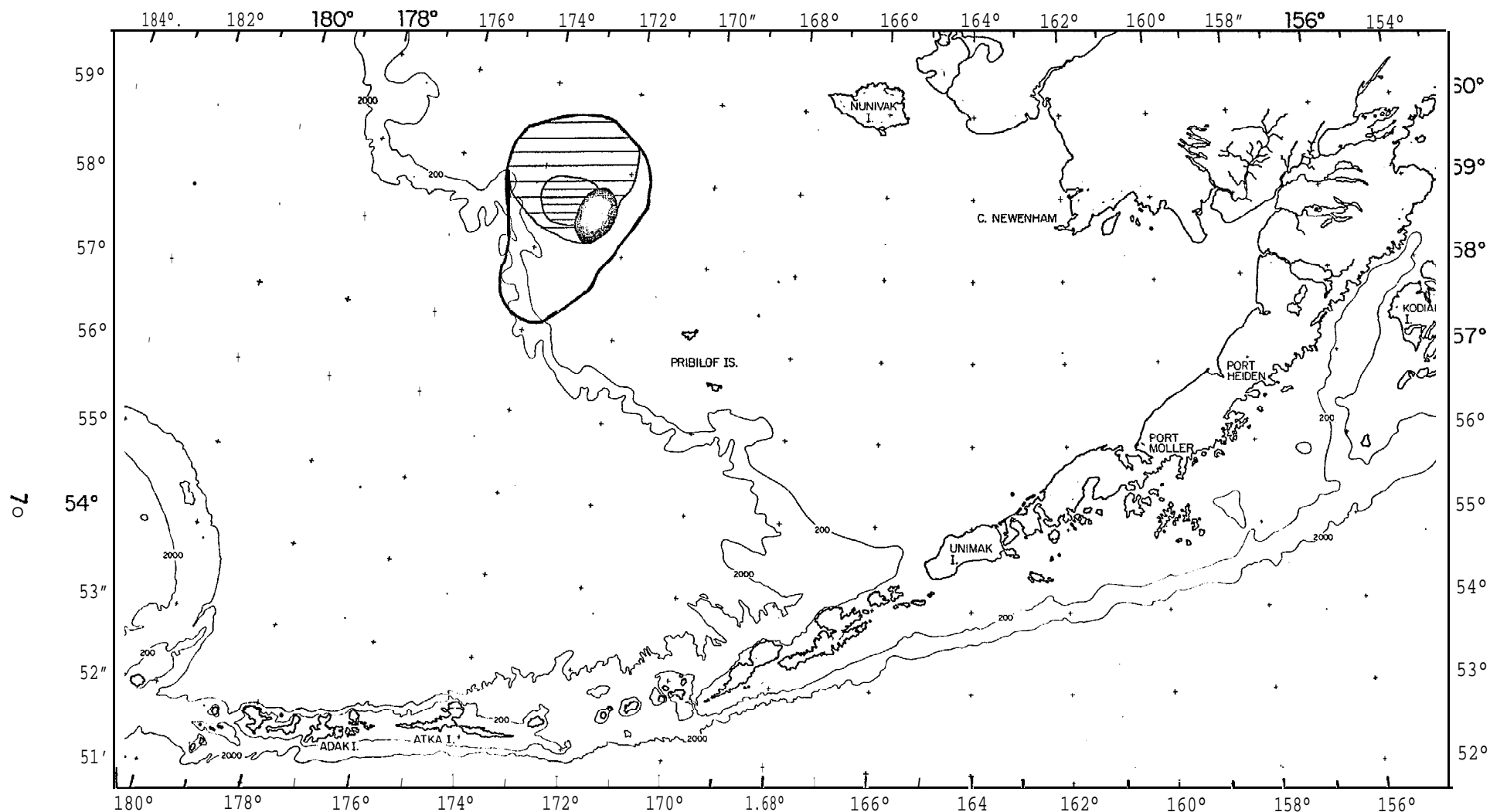
Figure 111.6.13 .--Distribution of herring in the eastern Bering Sea, November 1964, based on catch per 30-minute standard trawl and night hauls of 30-50 shackle gillnets of various meshes (modified from Rumyantsev and Darda 1970). Legend: — area of investigations; _____ - catches of individual fish; ===== tens of fish; -- tenths of metric tons (centners).

Rounsefell listed the following independent populations of Pacific herring in the Gulf of Alaska (Figs. 111.6.14, 111.6.15): Chatham Strait, Stephens Passage, Prince William Sound, Kachemak Bay-Shuyak Strait, Shearwater Bay-Old Harbor, Chignik and Shumagin Islands. In addition, Dahlgren (1936) believed that the entire coastline of the west coast of Baranof Island (southeast Alaska) was inhabited by one stock of herring that migrated to Cape Ommaney during the feeding season and back again for spawning the following spring. Over the years these populations have fluctuated greatly in abundance, and in some instances they decreased to nothing.

Very little is known about the distribution in the Gulf of Alaska of younger age groups of herring in their first year (length 60-70 mm) except that Rounsefell said they can often be seen in immense numbers never far from shore. He found that herring in their second year, about 120-140 mm in body length, were very numerous in inlets during summer months.

Mature herring are found as they approach shore during the spawning period, and after spawning they may disappear for a time (Rounsefell 1930a). Rounsefell found schools of fattening herring in late May in Chatham Strait, southeastern Alaska, and schools of fat herring were caught there until August, after which most of the herring were taken off Cape Ommaney at the mouth of the strait in September. In Prince William Sound, fattening herring were found in early June and part of July, and schools of herring of larger size occurred in late September and October.

In the Kodiak Island area, Rounsefell wrote that large, fat, mature herring were found in Shuyak Strait in July and may have remained during part of August. About six weeks after the schools appeared in Shuyak Strait, schools of large herring appeared in Kachemak Bay (Cook Inlet) and worked up the bay to occur off Halibut Cove in September and October. Herring of all sizes apparently wintered in Halibut Cove and the lagoon.

Rounsefell further noted that herring *were* found in " . . . winter months in some of the bays in southeastern Alaska where they do not usually occur in any quantity during the summer; for example, Ernest Sound, Stephens Passage, and Klawack Inlet, all of which are close to "spawning grounds."

Determinants of Distribution

The distribution of herring is related to several environmental and biological factors. Gershanovich et al. (1974) concluded that the formation of dense concentrations in the Bering Sea is distinctly seasonal. Herring are distributed in mid--water throughout the Sea during the warm period in connection with spawning and feeding and do not form large concentrations. When temperatures of mid-water layers cool in winter, the herring concentrate in near-bottom layers of 1.5 to 3.5°C. In spring, when waters warm and sex products mature, the herring rise from deeper water layers to upper layers (Svetovidov 1952).
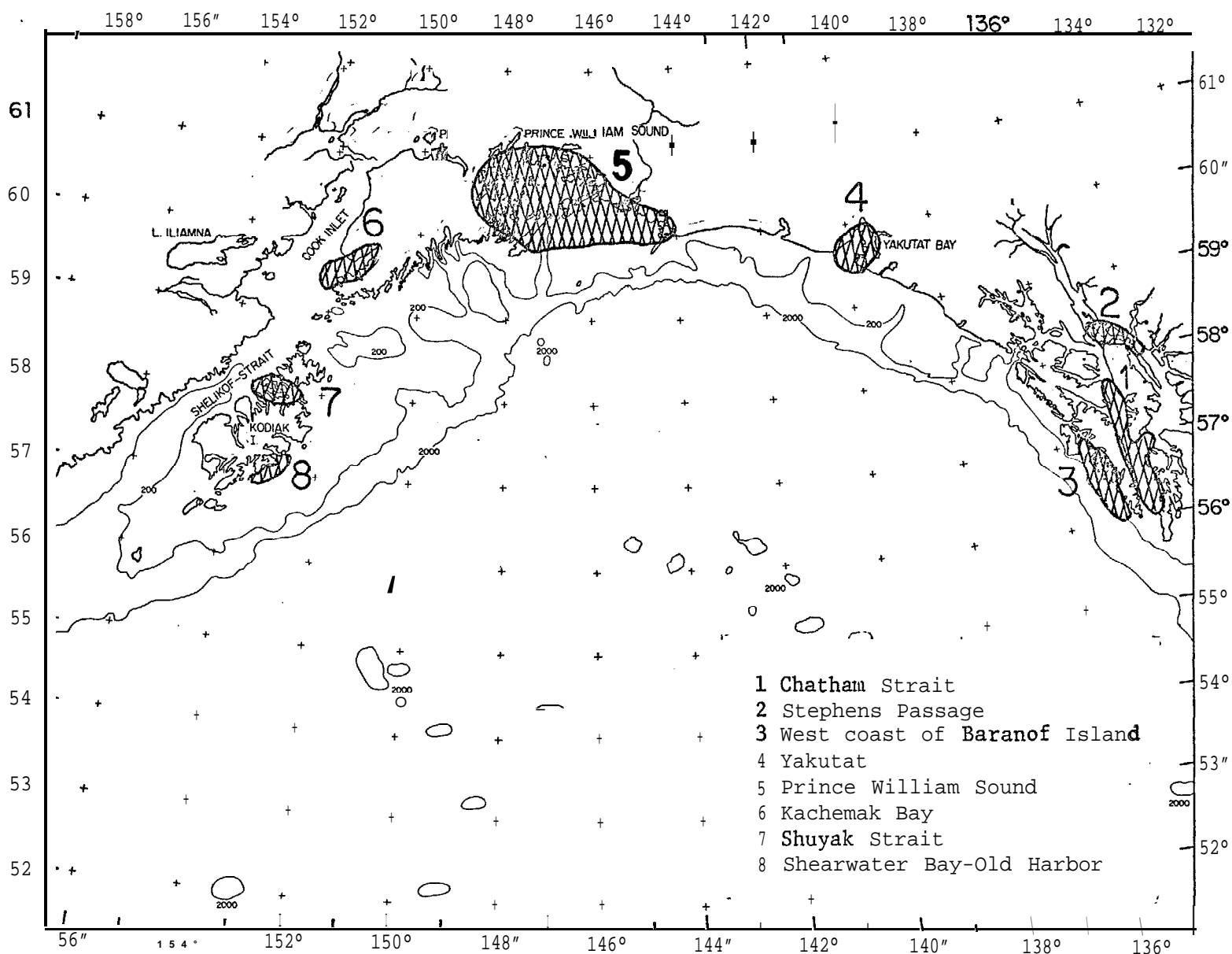
Figure 111.6.14.--Past or present populations of Pacific herring in the Gulf of Alaska (after data from Cobb 1906, Rounsefell 1930a).

1 Chatham Strait
2 Stephens Passage
3 West coast of Baranof Island
4 Yakutat
5 Prince William Sound
6 Kachemak Bay
7 Shuyak Strait
8 Shearwater Bay-Old Harbor

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Figure III.6.15.--Past or present populations of Pacific herring in the western Gulf of Alaska (after data from Cobb 1906, Rounsefell 1930a).

1 Chignik
2 Shumagin Islands
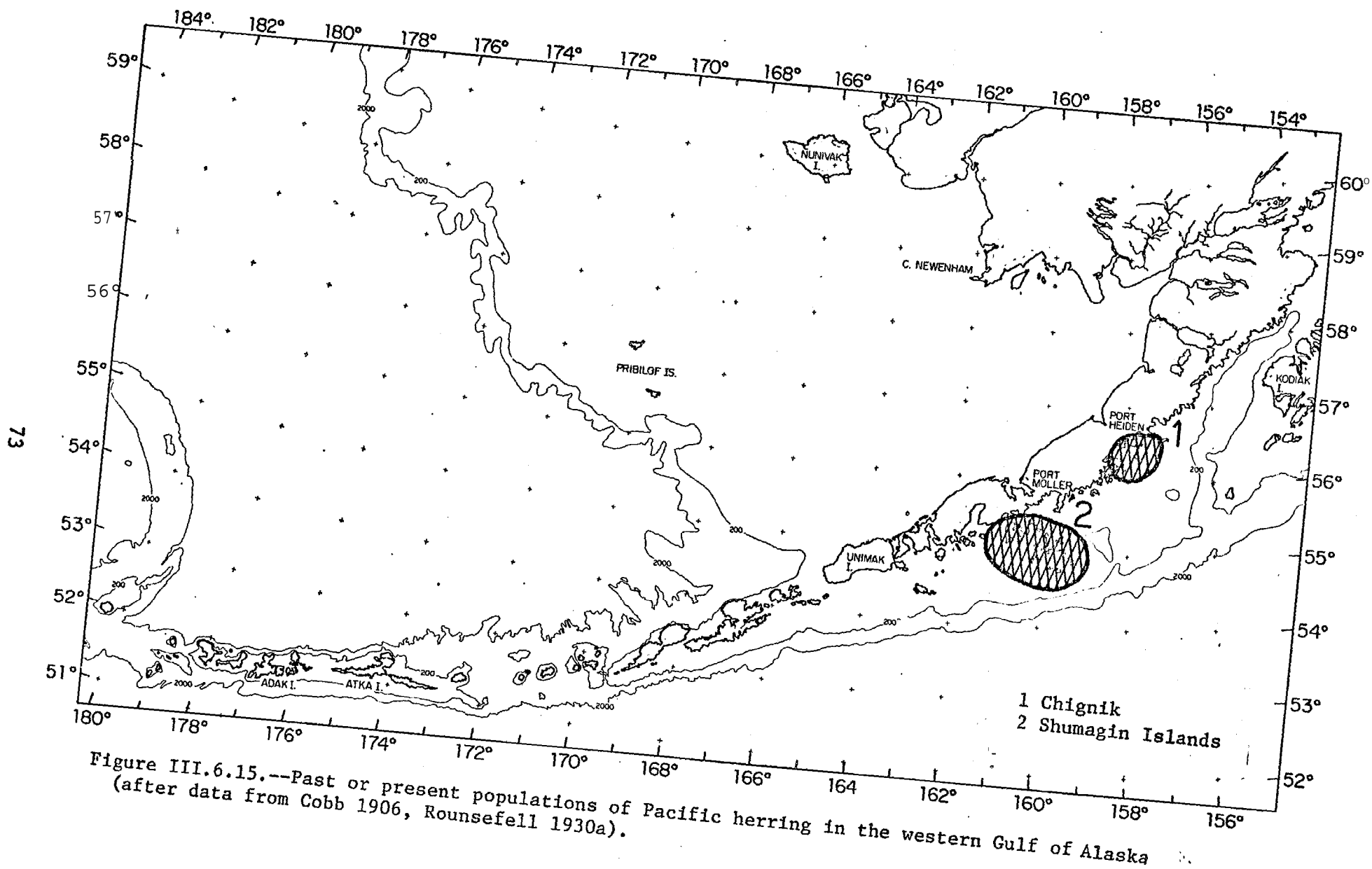
The water temperatures in which herring are found near the **Pribilof** Islands
in winter are higher than those of the Kar"aginski"i population (western part
of the Bering Sea) which winters in water temperatures of $0.5-1.2°C$ (**Prokh-**
orov 1968). Wintering herring in the **Pribilof** Island area move southeast
to warmer bottom waters during severe winters according to Shaboneev (1965).
Dudnik and **Usol'tsev** (1964) could not establish a relationship between water
temperature and distribution, however, and found herring in spawning migra-
tions at temperatures below zero (as low as $-1.7°C$). Shuntov (1963) stated
that the negative temperatures that cause them to move to deeper waters
in winter are not barriers during spring and summer migrations.

Although he discussed Far Eastern herring in general and did not specifically
refer to herring of the eastern Bering Sea or Gulf of **Alaska,** Kaganovskii
(1955) stated that optimum temperatures differed for juveniles and various
ages of sexually mature herring---spawning fish, feeding fish, and winter
fish. He said herring, as **a rule,** avoid the **thermocline.** In Peter the Great
Bay (U.S.S.R. waters), mass spawning of older herring is at 0 to 2°, young
herring spawn at 3°, and smallest herring may spawn at $5°C$. Feeding is carried
out at 4° to 15*C, and wintering at -1° to $+1.5°$ and higher, with variations
in **different** areas.

Distribution of Pacific herring is also influenced by availability of food
which is related to radiation, water temperature and other hydrological
conditions. Herring are found, particularly during the fattening period,
in areas with increased biological productivity on the continental **shelf**
where strong mixing of waters occurs to cause upsurge of **biogenous** elements
(**Shuntov** 1963). Herring are zooplankton eaters and, according to Rumyantsev
and Darda (1970), herring in the eastern Bering Sea avoided areas with heavy
phytoplankton blooms of 1-3 g/m in July-September 1964 (Figs. III.6.6⁻
111.6.9). This negative reaction of herring to **phytoplankton** has been noted
by other authors cited by Rumyantsev and **Darda,** particularly Henderson et
al. (1936) who **claim** that avoidance of areas with heavy blooms is because
the nutritional value of **phytoplankton** is low and certain algae settle on
the gills of herrings and interfere with respiration. **Rumyantsev** and **Darda**
concluded that only **non-commercial** quantities of herring are found in open
waters of the eastern Bering Sea and shelf in summer because of the mass
development of **phytoplankton.**

Salinity is another factor influencing distribution, but the relationships
are different at different stages **in** the life cycle of the herring (**Kaganov-**
skii 1955). Waters in which the Pacific herring live usually have a reduced
salinity (**Outram** and Humphreys 1974). In Canadian waters, Hourston (1953)
found evidence indicated a highly significant preference of herring for
less **saline** water of 31.09-31.59 **o/oo,** although the sampling was insufficient
to consider the relationship conclusive. Pacific herring have been reported
in some instances **to** spawn and remain for considerable time in estuarine
areas with high fresh water content (Kaganovskii 1955). Kaganovskii cites
I. G. **Fridliand** (1951) as stating that herring may spawn at salinities of
10-12 **o/oo** on the **Sakhalin** coast although salinities normally are high there.
Distribution of different age groups of herring in the eastern Bering Sea
in September and October 1964 and the salinity during those months are shown
in Figs. 111.6.10 and 111.6.12.

LIFE HISTORY

Reproduction

Pacific herring in North American waters spawn from late winter to late
spring, depending upon the geographic location. Southern populations usually
spawn earliest, and spawning occurs later to the north and west (see Table
111.6.1), although Skud (1959) noted local examples in southeastern Alaska
where the northerly and westerly progression in spawning time described
by Rounsefell (1930a) did not apply.

Table 111,6.1.--Season and water temperatures for spawning of Pacific
    herring in North American waters,

Area	Time	Water temp °C	Source
California	January-April	8.0-10.0	Scattergood et al. 1959
Oregon	January-Apri 1	3.8-12.3	Scattergood et al. 1959
British Columbia	February-early June	4.5-10.0	Outram and Humphreys 1974
Southeast Alaska	March-early June	6.1-11.0	Scattergood et al. 1959, Skud 1959
Prince William Sound	April-May	--	Rounsefell 1930a
Kodiak Island	Late Apr.-early June	(4.0-9 ?)	Kasahara 1961
Western Alaska	April-May	3,0-5.5	Scattergood et al. 1959
Unimak Island and north-west coast of Alaska Pen. (SE Bering Sea)	May	--	Rumyantsev and Darda 1970
Cape Newenham to Cape Romanzof (northeast Bering Sea)	May-early June	--	Rumyantsev and Darda 1970

The same spawning beaches in some areas are used every year, but times and
locations may change in other areas. According to Skud (1959), the initial
spawning in southeast Alaska each year occurs in the vicinity of Craig during
late March. Spawnings follow at Kah Shakes, Sitka, and Auke Bay and are
usually completed in early May. Spawning times vary in Behm Canal, Etolin
Island, and Frederick Sound and have been reported in late April, May, and
early June.

In Prince William Sound and Cook Inlet, spawning was reported to occur in
April and May (Rounsefell 1930b). Spawning in the Kodiak-Afognak Island
area took place in May and June according to Scattergood et al. (1959),
although Kasahara (1961) and Reeves (1972) list the time as being late April
to early June.

Spawning begins in May in the southeastern Bering Sea and occurs later (June-July) in the northern part. Herring spawn at Unimak Island and Unalaska and the northwest coast of the Alaska Peninsula in April-May (Dudnik and Usol'tsev 1964, Rumyantsev and Darda 1970, Warner 1976). Spawning areas on the north coast of the Alaska Peninsula are, in order of importance, Herendeen Bay, Port Heiden, and Port Moller (Warner and Shafford 1976). Shaboneev (1965) reported that a small number of herring apparently spawn near the Pribilof Islands. Spawning areas of the eastern Bering Sea are noted on Fig. 111.6.2.

Spawning populations appear along the western Alaska coastline about mid-June to early July. The peak of spawning activity along the northern coast of Bristol Bay (Togiak Fishing District) usually occurs in late May to the first week of June (Barton 1976). Herring spawn in the shallows in the Nunivak Island area (Shaboneev 1965), and prespawning herring were found there in the second half of June (Dudnik and Usol'tsev 1964).

Age and Size at Maturation

The age and size of Pacific herring at maturation vary with the geographic area, but they generally mature at age 3 or 4 in both the eastern Bering Sea and the Gulf of Alaska. Reeves (1972) stated that herring in Alaska waters mature at approximately age 3 or 4 and length of 15-20 cm, and fish older than 6-7 years and larger than 30 cm are rare. In the eastern Bering Sea, herring spawn for the first time at ages 2-6 and lengths of 19-26 cm (Shaboneev 1965, Rudomilov 1972), but only a few (generally males) mature at age 2 (and a length of 18 cm) according to Rudomilov. Shaboneev reported that roughly half of the fish mature after four years of life, and Rumyantsev and Darda (1970) found 95% of 5-year-olds were mature. Rounsefell (1930a) analyzed age at maturity of herring from several localities in Cook Inlet and southeastern Alaska. He found no mature 2-year-olds, 32-84% of the 3-year-olds were mature, 60-100% of the 4-year-olds, and all of the 5-year-olds were mature.

Fecundity and Gonads

Fecundity is related primarily to body length and to a lesser extent depends on age, independent of its effect on body length (Nagasaki 1958). In British Columbia, fish spawning for the first time averaged 12,000 eggs and the oldest fish averaged 30,000 eggs (Fraser 1922). The number of eggs per female in Pacific herring ranges from 10.8 to 134 thousand and averages 72.2 thousand according to Berg et al. (1949). The figures from Berg et al. must be based predominantly on Asian populations, however, because fecundity in North American waters is lower (average 20,000 in British Columbia according to Hart and Tester 1.934). Rudomilov (1972) found the fecundity of Pribilof area herring of 19.5-34 cm in the eastern Bering Sea in 1970 was 10.4-112.6 thousand eggs (average 46.2 thousand). In comparison, the range of fecundity of Korfo-Karaginsk (eastern Kamchatka) herring of 24-31 cm was '17.5-70.5 thousand eggs in both 1970 and 1962, with an average fecundity of 40,350 in 1970 and 34,150 in 1962 (Fig. 111.6.16). Comparative fecundity of Pribilof herring was 130-385 eggs per gram of body weight without' viscera (Fig. III. 6.17). Warner and Shafford (1976) examined spawning fish of ages 4-6, length 19.2-27.6 cm, weight 80-312 g, and found a fecundity of 12.7-84.9 thousand eggs with a mean of 26.5 thousand in inshore waters of the eastern Bering Sea,

Number of eggs (thousands)
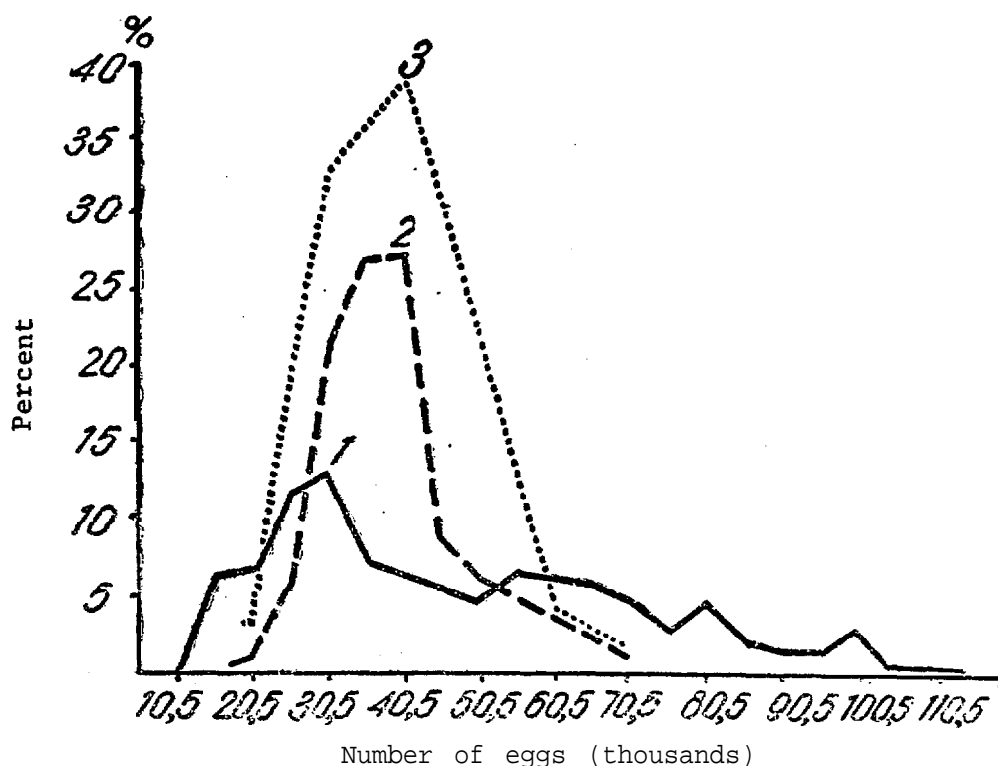
Figure 111.6.16 .--Individual absolute fecundity. of female Pribilof
(1) and Korfo-Karaginsk (2,3) herring. 1-1970, N=215, M-46.2 + 23,
C=52.7%; 2-1970, N=124, M=40.35 + 8.05, C=19.9%; 3-1962, N=170,
M=34.15 + 8.6, C=25.1%. (From Rudomilov 1970).
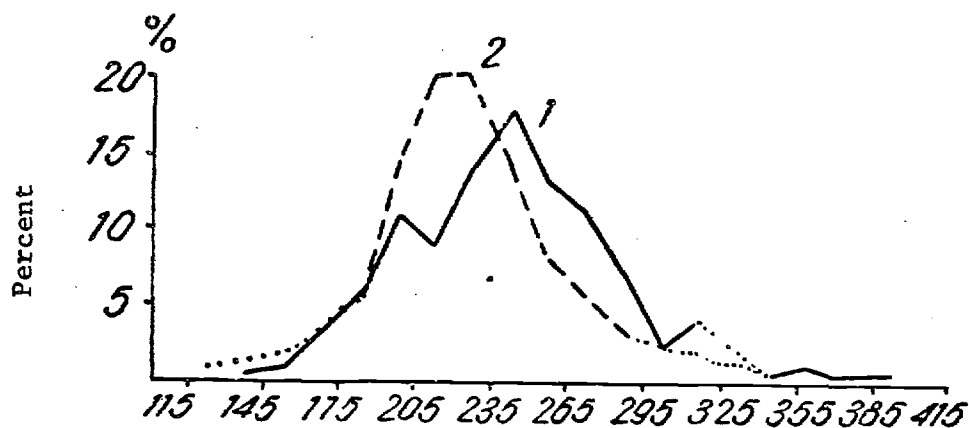
Number of eggs per gram of weight of eviscerated fish.

'Figure 111.6.17 .--Comparative fecundity of female Pribilof (1) and
Korfo-Karaginsk (2) herring in 1970 in number of eggs per gram of
weight without viscera. 1-N=215, M=242.7 + 40.5; 2-N=124, M=225.6 +
34.5. (From Rudomilov 1970).

Milt and roe comprise a large proportion of the total weight of the herring before spawning according to Fraser (1915). In British Columbia, the largest male gonad weighed 22.7 g from a 158 g fish, and two gonads were 28% of the total weight of the fish. The largest female gonad was 18.6 g from a 151.5 g fish, the two gonads totalling 24% of the total weight. Fraser noted that younger and smaller fish apparently have proportionate gonad weights. Ripe eggs are 1.4-1,6 mm diameter and in weight are 900-1,000 per gram of ovary weight. Kachina and Akimova (1972) found gonad weights of Korfo-Kara-ginsk herring in the first year of life in 1970 were 20 mg for females and 3 mg for males.

The gonads are empty for some time after spawning and they show little evidence of renewal before the end of the third month (Fraser 1922). At the end of four months the eggs are small and each gonad weighs less than a gram; the weight is 2-5 g after six months. Prokhorov (1968) observed that large males have a lower fatness in autumn than do females, presumably related to intensive accumulation of sperm, because testes develop faster than ovaries at that time. Rapid growth of ovaries begins in the pre-spawning period in spring.

Mating and Fertilization

At spawning time, the schools of mature herring move in large numbers into shallow waters at high tide to spawn. The eggs are usually deposited on vegetation in sheltered bays, along steep or. shelving rocky shores, or along open sand beaches (Taylor 1964). The intertidal spawning zone is from about $3\frac{1}{2}$ meters above to slightly below the zero tide level, according to Taylor, and temperature and salinity may vary considerably.

Spawning takes place in water depths of less than one meter to 12-15 meters at temperatures of -0.8 to 15°C (Berg et al. 1949, Musienko 1970). Experiments and observations show that Pacific herring eggs can be fertilized at salinities of O to 70°/00 but ranges of 7 to 40°/00 are optimal (Dushkina 1973). The number of fertilized eggs decreases at salinities higher than 30°/00 and at 5°/00 (Galkina 1957). Musienko reported that the principal approaches and spawning of herring occur at temperatures up to 5.5°C and salinities of 5-30°/00. Comparable ranges were mentioned by Alderdice and Velsen (1971) who stated that the abundance of herring is related to the availability and extent of spawning salinities between 8 and 28°/oo. They added that the population abundance in North American waters is associated with spawning temperatures of 5-9°C, is limited by temperatures of 9-10"C, and the maximum temperature for spawning is about 10"C. The lower limit of thermal tolerance is between 4 and 5°C. East Kamchatka herring approach for spawning in a period of rising water temperatures of 2.2 to 7°C, and the main run occurs at 3-6°C (panin 1950).

The vegetation upon which the adhesive eggs are deposited varies with the locality, and the eggs also may be attached to gravel, boulders, logs, and tree limbs. Taylor (1964) found that the dominant substrate in sheltered bays and on sandy beaches in British Columbia was eelgrass (Zostera marina and Phyllospadix scoulerii), along rocky shores it was rockweed (Fucus evanescens), and in some localities was a brown alga, Japweed (Sargassum muticum).

Some spawning in deeper water occurred on a" large brown alga, oarweed (Lamin-aria sp.). In southeastern Alaska, eggs were attached to Zostera, Fucus, and vine kelp (Macrocystis) in an area of gently sloping gravel beaches, but in an area of steep, rocky shores the eggs were found on Fucus in the intertidal zone and on beds of bladder kelp (Nereocystis) in deeper water (Skud 1959).

The spawning act has been described by Fraser (1915, 1922) and Rounsefell (1930a). In spawning, the female quivers from head to tail and she swims, turns on her side, and moves among the seaweed or eelgrass, extruding eggs in a thin stream as she rubs against the vegetation or other objects. The eggs are coated with a gummy secretion and adhere immediately to whatever they contact as well as to each other. Although the numbers of" males and females are approximately equal, there is no pairing of males with females, but the males move about expelling a stream of milt on the eggs. After spawn-ing, the herring move out into deeper water (Fraser 1915).

The milt is so abundant that the water becomes greenish-white and almost opaque. Hourston and Rosenthal (1976) took sperm samples in a spawning area near the Pacific Biological Station, Nanaimo, B.C. and found that the sperm density varied between 80 and 210 sperm/ml. The average density in the area of maximum discoloration for two spawnings was 148 and 129 sperm/ml. They reported that studies by H. Rosenthal showed the herring sperm is chemically attracted to the surface of the egg from a distance of at least 0.1 mm, and each egg, under specific conditions of egg deposition and egg size, would attract 24 sperm when the sperm density is 150/ml. Spermatozoa survive longer, up to 7 to 8 days, at low salinities (0.3 to 0.5 °/oo), but their "activity decreases sharply (Dushkina 1973).

According to Fraser (1915), almost all eggs are fertilized unless they are laid too close to the surface so that the water subsides before they are fertilized or unless they are covered in some quiet spot immediately after deposition. They often are exposed at low tide perhaps four or five hours but may not be harmed if attached to plants or other organic material that retains moisture.

The eggs may be deposited in several layers, best larval production is found when spawn depositions are of light to medium intensity, and about 2 to 4 layers of eggs apparently is the optimum density for maximum larval produc-tion (Taylor 1971a). Thick and multilayer spawn consists of 3 to 5 layers, but in the Okhotsk Sea as many as 6-15 and even 16-20 layers were observed (Galkina 1971). Galkina estimated the density of egg deposition on such spawning grounds was 1-2 and even 5 million per square meter, and Svetovidov (1952) listed the maximum density in southern Sakhalin as 17.5 eggs per square meter. Fraser (1915) had even higher density estimates of a minimum of 10,000,000 per square foot (0.1 square meter) in British Columbia, and he said a piece of eel grass six inches (15.2 cm) long might have 300,000 eggs.

Growth and Nutrition

Growth

The eggs develop in 12-50 days (Berg et al. 1949, Musienko 1970), depending
on the water temperature. Rounsefell (1930a) found the average time in the
Prince William Sound Region was 12 to more than 21 days. Normal development
occurs at temperatures of 0.5-9.2°C and salinities of 6.7-25.8°/oo (Berg
et al. 1949). Differences in development rates of embryos in various layers
of eggs (in multilayer spawning) are caused by variations in the degree
of oxygen penetration and the possibility for removal of metabolic products
(Galkina 1971). Alderdice and Velsen (1971) advanced the hypothesis that
maximum numbers of viable larvae of largest size at median hatching time,
produced in the shortest incubation period, and reaching near-maximum size
at the stage of yolk absorption in greatest numbers would be produced by
incubation conditions at or near salinity 16.98 '/00 and a water temperature
of 8.7°C.

Fraser (1915) describes the development of the egg after fertilization,
and Fraser (1922) and Stevenson (1962) review the development and growth
of larvae. The larvae at hatching are 4-8 mm long and average about 6 mm
standard length according to Stevenson. The newly-hatched larvae are thin
and threadlike, semi-transparent, scaleless, and are carried to and fro
by currents and tides because they are able to swim only feebly. About 30-
40 days after hatching they are 20-25 mm long (Tester 1935, Berg et al.
1949). When they reach 35-40 mm after 40-70 days, they have metamorphosed
into a juvenile, herring-like shape, scales have begun to grow, and they
swim actively in schools near the spawning grounds (Fraser 1922, Stevenson
1962, Taylor 1964). In six months the fish are about 60 mm and in a year
are 90-100 mm in length (Fraser 1922).

Rounsefell (1930a) stated that knowledge of growth rates in various localities
is desirable because determination "of whether a difference in average size
of fish between two areas is caused by difference in growth rate or by differ-
ence in age composition is important in studying depletion. Where differences
in growth rate are great, the differences show lack of migration and independ-
ence of the areas. Growth curves of herring from Dutch Harbor (Unalaska
Island), Halibut Cove (Cook Inlet), Elrington Passage (Prince William Sound),
and Stephens Passage (southeast Alaska) as determined by Rounsefell are
shown in Fig. 111.6.18. He noted that the growth curve for Stephens Passage
was not representative of southeast Alaska as a "whole but was comparable
to that of British Columbia herring. He also found a tendency for slower
growth in the southern and eastern portion of the range, but the growth
rate in each general area was slower in inclosed waters.

The most intensive growth of herring in the eastern Bering Sea occurs during
the first year when they reach 9.1 cm (Shaboneev 1965). In subsequent years
the growth rate declines, and annual increments during last years of life
do not exceed 0.7 cm (Tables 111.6.2, III.6.3). Comparable annual increments
were shown by Dudnik and Usol'tsev (1964) who found that the maximum annual
rate of growth was until the age of three years. Shaboneev analyzed the
specific growth rate and the growth constant and found that the growth of

herring can be divided into four periods (Table 111.6.4). The first is a period of intensive growth of sexually immature fish; the second and third periods reflect growth of fish that are sexually immature or spawn the first time; the fourth period is that of the growth of sexually mature herring.
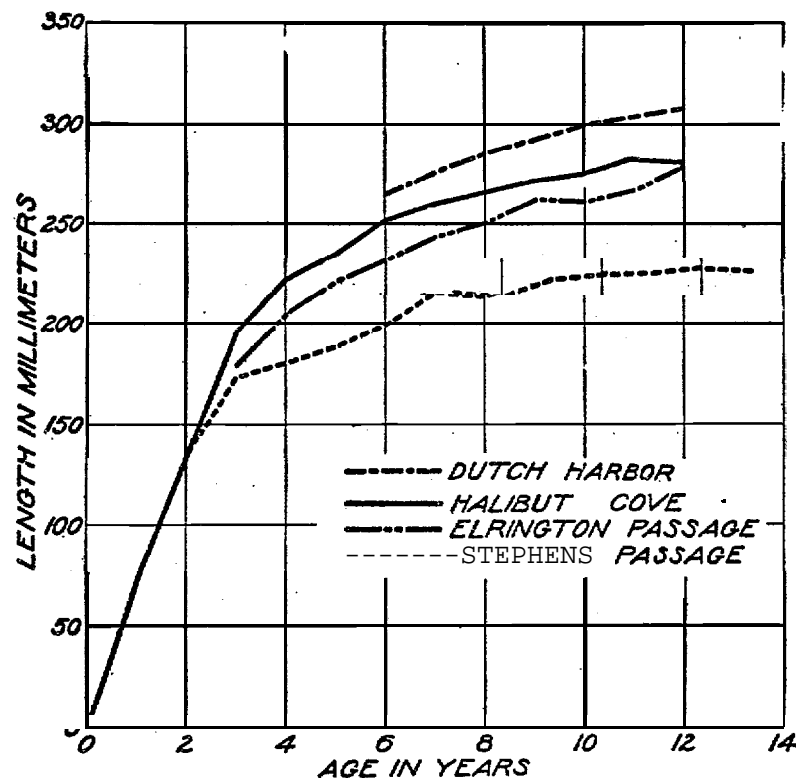
Figure III.6.18.--Growth curves of herring from various areas of Alaska, showing the age-length relationship (from Rounsefell 1930a).

Table 111. 6.2 .--Growth rate of herring (mm) in the eastern Bering Sea (from Shaboneev 1965).

Age	l_1	l_2	l_3	l_4	l_5	l_6	l_7	l_8	l_9	l_{10}	No. of fish
3	92	170	215								**9**
4	94	161	205	233							**161**
5	84	160	208	233	249						145
6	89	161	202	236	261	216					16
7	96	160	195	235	261	278	289				27
8	89	157	200	237	260	278	291	300			**10**
9	88	158	201	234	254	272	284	293	302		.**9**
10	98	158	195	229	254	278	288	293	302	315	**2**
Average	91	160	202	234	256	276	288	295	302	315	**379**

Summer and winter herring of the eastern Bering Sea have similar growth "rates, but growth rates of different year-classes show some differences, according to Rumyantsev and Darda (1970). They stated that certain differences in growth rates which appear principally in the first two years do not show thereafter.

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Table 111.6.3 .--Annual growth increments of herring (cm) in the eastern Bering Sea (from Shaboneev 1965).

Age	1	2	3	4	5	6	7	8	9	10
Growth increment	9.1	6,9	4.2	3.2	2.2	2.0	1.2	0.7	0.7	1.3

Table 111.6.4. --Specific growth rate and growth constant of herring in the eastern Bering Sea (from Shaboneev 1965).

Age	Length, cm	Specific growth rate	Growth constant	Average growth constant
1	9.1			
		0.564	0.863	0.863
2	16.0			
		0.233	0.582	
3	20.2"			0.s46
		0.146	0.511	
4	23.4			
		0.085	0.382	
5	25.6			0,397
		0.075	0.412	
6	27.6			
		0,042	0.273	
7	28.8			0.213
		0.023	0.172	
8	29.5			
		0.023	0.195	
9	30,2			
		(?.042	0.399	
10	31.5			

According to Thompson (1917), "The rate of growth found for samples from different localities is shown to correspond to the average size reached, when the methods and intensity of fishing are considered." Rounsefell and Dahlgren (1935) examined growth of herring from several localities of southeast Alaska. They wrote that herring from four localities grew much slower than those of other localities in the area and represented groups of fish separate from neighboring stocks or populations: Noyes Island area (including Culebra Island and Port Estrella), the Douglas Island-Icy Strait area, Affleck Canal (Ken Bay), and Peril Strait (Todd). The Peril Strait herring appeared to be slowest growing of any the authors encountered in Alaska, but Moberly and Thorne (1974) found slowest growth in the Auke Bay area (Douglas Island area of Rounsefell and Dahlgren). Moberly and Thorne also reported Carroll Inlet fish were the fastest growing for a given age from several populations in southeast Alaska.

Food and Feeding

After the herring hatch and the yolk-sac is absorbed, they will die unless they find appropriate food. First success of herring feeding depends on the searching power of the larvae, their ability to catch food and the abundance of suitable plankton (Blaxter 1965). The first food of larvae is limited

to small and almost immobile plankton organisms that the larvae must nearly
literally run into to notice and capture (Nikitinskaya 1958). Earliest food
is sometimes more than 50% microscopic eggs, and other items are diatoms
and young or nauplii of small copepods (Tester 1935). Nikitinskaya estimated
that newly-feeding larvae required densities of 22,000 organisms/m^3 or a
biomass of 20-50 mg/m^3 for sufficient nutrition. Herring do not have a strong
preference for certain food species but feed on the comparatively large
organisms that predominate in the plankton of a given area (Kaganovskii
1955),

Wailes (1935) made a detailed study of food and feeding of herring at various
stages of development and presented a table listing more than 90 kinds of
food found in herring stomachs in British Columbia. His determinations of
the relative importance of major food organisms of various herring length
groups are shown in Fig. 111.6.19. Copepods were found to be the most impor-
tant food organism on the whole. Postlarval fry (2o-1oo mm) consumed the
greatest variety of food which, in order of importance, included Copepoda,
Cirripedia, Mollusca, various ova, Bryozoa, Cladocera, Rotifera, Decapoda,
and Euphausiacea. Food of adults was almost entirely Crustacea, dominated
by Euphausia pacifica, with Copepoda forming the rest of the diet (along
with occasional herring eggs). The vast numbers of copepods that may be
consumed was demonstrated by a count of 3,000 copepods in the stomach of
a 66 mm herring (Fraser 1922). Fraser mentioned other occasional diet may
be ascidian larvae and peridinia.

Somewhat different food preferences have been reported in the Bering Sea.
In November-December in Kamchatka waters of the western Bering Sea, Kachina
and Akimova (1972) found that juvenile herring consumed small and medium
forms of zooplankton (Chaetognaths, copepods, tunicates) and benthoplankton
(mysids). Euphausiids, amphipods, mollusks, and other organisms were found
rarely and usually in small quantities. In the same general area, Rass et
al. (1955) stated that calanoid copepods comprise 77% (by weight) of food,
Thysanoessa (euphausiid) occupies up to 9%, and Mysidae to 7%. In the demersal
zone, herring stomachs contained quantities of tubes of polychaete worms,
bivalve mollusks, amphipods, copepods, juvenile fish, and detritus.

In the eastern Bering Sea, stomachs in August were 84% filled with euphau-
siids, 8% with fish fry, 6% with calanids, and 2% with gammarids (Rumyantsev
and Darda 1970). Fish fry in order of importance, were walleye pollock,
smelt, capelin, and sandlance. In spring, food was mainly Themisto (Amphi- .
pods) and Sagitta (Chaetognatha), and after spawning the main diet was euphau-
siids, Calanus, and Sagitta (Dudnik and Usol'tsev 1964).

The intensity of feeding varies with area and time of year. Mature herring
feed most intensively in the spring after spawning and during the summer
(Tester 1935, Rass et al. 1955), and they feed lightly in fall and winter
(Kachina and Akimova 1972). In the eastern Bering Sea, wintering herring
rarely eat but begin foraging in May and June after spawning, according
to Dudnik and Usol'tsev. Rumyantsev and Darda (1970) determined, however,
that herring on the eastern Bering Sea shelf outside the 20-mile limit have
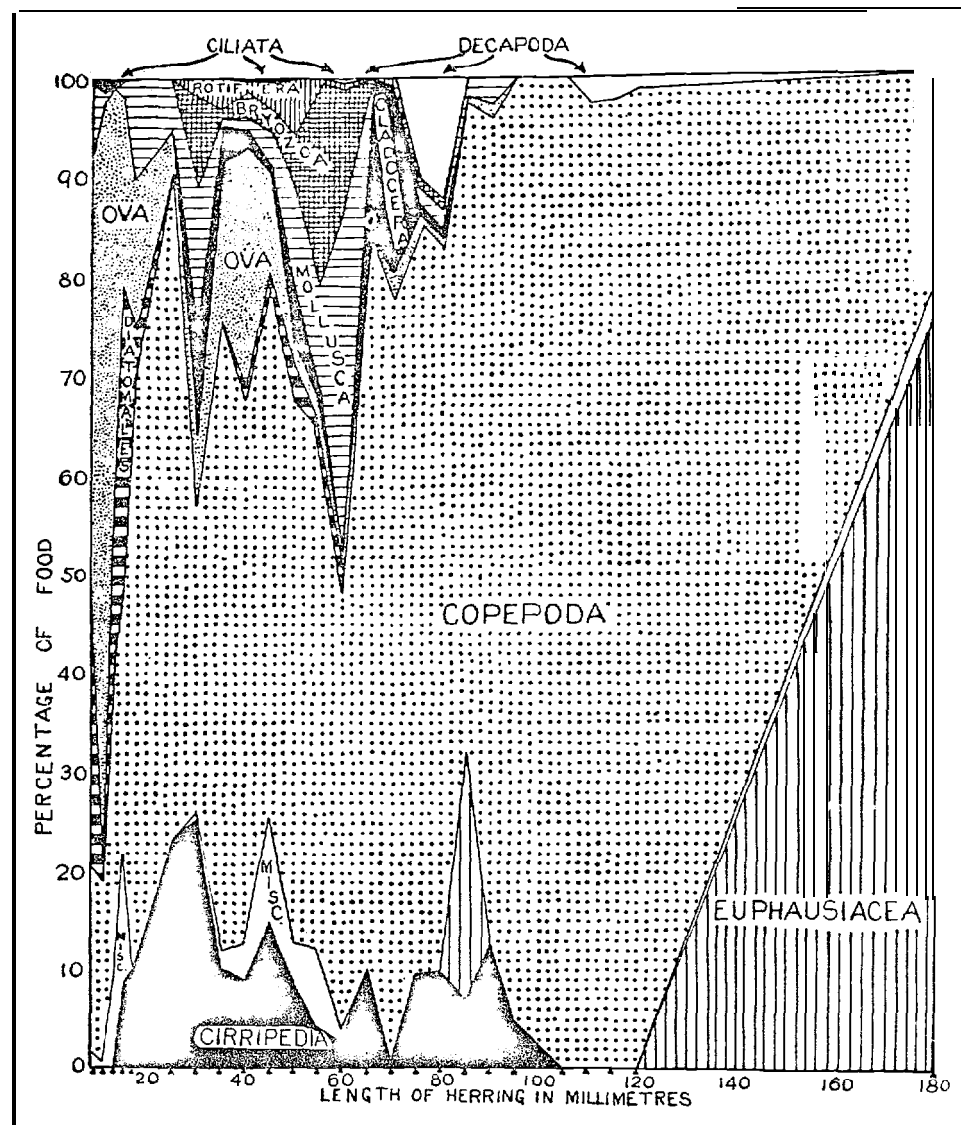
Figure 111.6.19. --Relative importance of the major groups of food organisms of herring at all stages of development. The positions representing the various length groups are indicated by the points immediately below the base line and the percentage of food of each kind for the length is shown by the vertical distance in the various areas above the point (from Wailes 1935).

poor feeding conditions. As a result, herring from that area, unlike those from areas with abundant food, do not cease feeding from March through October. Figure 111.6.20 shows seasonal variation in food items, feeding intensity, and condition of herrings in the eastern Bering Sea as determined by Rumyantsev and Darda.
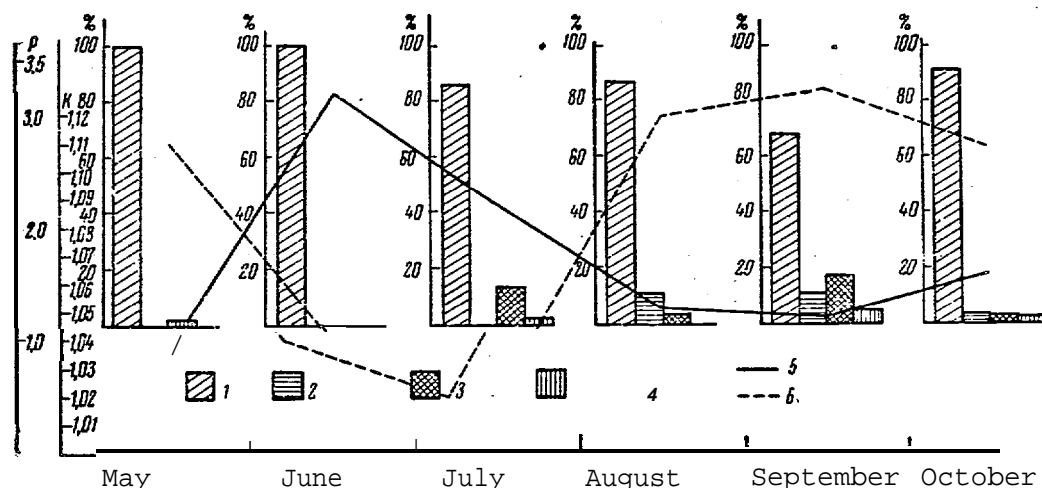
Figure 111.6.20 .--Composition of diet, feeding intensity and condition of herrings in the eastern Bering Sea: 1-euphausiids, 2-calanids, 3-fish fry, 4-gammarids, 5-P-feeding intensity, 6-k-Fulton's condition factor (from Rumyantsev and Darda 1970).

Predators and Competitors

Herring are preyed upon at all stages of their existence by a number of invertebrates, fishes, birds, and mammals (Table 111.6.5), but the importance of herring as a food item for predators varies in the same areas in different months and years. At spawning time when herring approach shallow waters in huge schools and deposit their eggs, the adults and the eggs are particularly vulnerable to their enemies. In Halibut Cove lagoon (Cook Inlet), Rounsefell (1930a) saw about 50 belukha (whales) raising havoc with herring schools and thousands of seagulls scattered everywhere. He wrote, "Cormorants, murres, surf scoters, and divers were there in tens of thousands, and scores of bald eagles were circling about." A week later, thousands of gulls were still present but they had been so thorough in feeding that the numbers of eggs were reduced to no more than one or two eggs per square inch.

In British Columbia, birds were estimated to cause a loss of 30-90% of herring spawn (Taylor 1955). Taylor (1964) commented, however, that although bird predation may be the greatest single cause of spawn mortality, it is fairly constant from year to year and thus may not be a particularly significant cause of variations in year-class strength. A study of predation by sea birds in Washington State in 1945, showed that cormorants, mergansers, western grebes, and loons fed on the adult herring, while scoters and scaups were the only waterfowl that removed quantities of eggs {Cleaver and Franett no date). Although stomachs of scaups averaged 6,184 herring eggs, surf scoters averaged 8,046 and white winged scoters averaged 11,945, only a small number of predators was sampled and the timing of the experiments precluded determination of the total effect of bird predation.

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Table 111.6.5.--Predators of Pacific herring.

Predator	Egg	Larvae	Juvenile or adult	Literature source
Invertebrates				
Chaetognaths (Sagitta spp.)		x		19,20
Ctenophora (Pleurobrachia spp)		x		19,20
Jellyfish spp.		X		19
Fishes				
Cod Spp.			x	3
Lingcod (Ophiodon elongatus)		x	x	22
Spiny dogfish (Squalus acanthias)	x	x	x'	4,7,10,22
Flounders spp.	x			4
Pacific hake (Merluccius productus)			x	16
Pacific halibut (Hippoglossus stenolepis)		x	x	22
Pacific herring (Clupea harengus pallasi)	x	x		7
Perch spp.	x			4
Salmon (Oncorhynchus spp.)		x	x	3,8,22
Chinook salmon (Oncorhynchus tshawytscha)			x	7,17
Coho salmon (Oncorhynchus kisutch)			x	17
Sharks spp.			X	3
Trout Spp.			x	22
Birds				
Cormorants spp.			x	4,18
Crows spp.	x			22
Divers (spp.?)			x	18
Ducks spp.	x			7,'22
Northern bald eagle (Haliaeetus leucocephalus alascanus)			X	18
Western grebe (Aechmophorus occidentals)			x	4
Sea gulls spp.	x		x	3,4,7,18.22
Loon spp.			x	4
Mergansers spp.			x	4
Murres spp.			x	18
Greater scaup (Nyroca marila)	x			4
Surf scoter (Melanitta perspicillata)	x		x	4,7,18.
White-winged scoter (Melanitta deglandi)	x			4

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Table 111.6.5.--Continued.

Predator	Herring life stage			Literature source
	Egg	Larvae	Juvenile or adult	
Mammals				
Dolphins spp.			x	3
Striped dolphin				
(Lagenorhynchus obliquidens)			x	23
Porpoises				
Dan's porpoise (Phoca dalli)			x	25
Harbor porpoise (Phocaena phocaena)			x	23
Sea lions spp.			x	22
Seals spp.			x	22
Fur seal (Callorhinus ursinus)			x	6,12,13,14,15,21,24
Harbor seal (Phoca vitulina)			x	9
Whales				
Belukha (Delphinapterus leucas)	—	—	x	1,2,5,18
Fin whale (Balaenoptera physalus)			x	23
Humpback whale (Megaptera nodosa)			x	11,23
Killer whale (Orcinus orca)	—		X	23
Minke whale (Balaenoptera acutorostrata)			x	23

1-Arsen'ev 1935 (cited by Kleinenberg et al. 1964); 2-Arsen'ev 1939 (cited by Geptner /Heptner/ et al. 1976); 3-Berg, Bogdanov, Khozhina, and Rass 1949; 4-Cleaver and Franett no date: 5-Dorofeev and Klumov 1936 (cited by Kleinenberg et al. 1964); 6-Fiscus, Baines, and Wilke 1964; 7-Fraser 1922; 8-Gilbert 1895; 9-Kenyon 1956; 10-Ketchen and Taylor 1971; n-National Marine Fisheries Service 1973-75b; 12-15 North Pacific Fur Seal Commission 1962, 1969, 1971, 1975; 16-Outram and Haegele 1972; 17-Pritchard and Tester 1944; 18-Rounsefell 1930a; 19-Stevenson 1962; 20-Taylor 1964; 21-Taylor, Fujinaga, and Wilke 1955; 22-Tester 1935; 23-Tomilin 1957; 24-Wilke and Kenyon 1957; 25-Wilke and Nicholson 1958. .

Studies by Stevenson (1962) showed that Ctenophora were greatest predators of herring larvae, consuming as many as 45% of the larvae in a sample. He concluded, however, that predation of ctenophores, jellyfish, and chaetognaths is probably generally not a serious cause of larval mortality.

At least 16 species of demersal, pelagic, and anadromous fish were found to feed on herring at certain times and places each year in British Columbia (Ketchen and Taylor 1971). The spiny dogfish (Squalus acanthias) constituted as much as 60% to 80% of the total (by weight) of the predator species. The importance of herring as food for chinook (Oncorhynchus tshawytscha) and coho salmon (O. kisutch) was examined in British Columbia waters in 1939, 1940, and 1941 (Pritchard and Tester 1944). Salmon (as well as dogfish) are opportunistic feeders, but the average volume of herring in chinook salmon stomachs ranged from 33.8 to 45.9% and that of coho salmon was 12.8 to 34.1%.

Numerous species of aquatic mammals are known to consume herrings, but the food habits of the fur seal (Callorhinus ursinus) have been the most thoroughly studied. Like many other marine predators, fur seals have a non-selective diet and feed on the most conveniently available food species. In studies previous to 1961 off southeast Alaska, herring contributed more than 50% of all fur seal food and in most cases over 90% but in the eastern Bering Sea, south of the Aleutian Islands, or near Kodiak Island, seal stomachs showed very few or no herring (Wilke and Kenyon 1957, Trumble 1973). A number of other fur seal food studies detail the variation of food items within and between seasons and areas (North Pacific Fur Seal Commission 1962, 1969, 1971, 1975; Fiscus et al. 1964). Those studies indicate that the highest volumes of herring in fur seal stomachs occur in winter and spring (January-May), and the lowest volumes are in summer and fall (June-October) (see Table 111.6.6).

The greatest numbers of herring obviously are consumed at times when quantities of fur seals and herring are in the same area at the same time. No determination of the total predation of fur seals on herring has been made because of the wide variations of fur seal food habits in offshore and inshore waters. Combined United States and Canadian data for 1967-72 indicated, however, that off Washington State and southwestern Vancouver Island, by volume herring comprised 18% of food species eaten by fur seals (North Pacific Fur Seal Commission 1975). Pacific erring contributed 25% of fur seal food by volume in December, January, and February and 13% by volume in March, April, and May.

Competitors of Pacific herring for food include other plankton-eating fish such as sardines, capelin, and sand lance (Berg et al. 1949) as well as pink salmon, mackerel, spiny dogfish and other fish (Svetovidov 1952). Svetovidov also lists jellyfish and Ctenophora as competitors, and he mentions that mass development of phytoplankton during summer feeding has a negative effect on the spread of the herring. In the Bering Sea, the principal food competitor of the herring is the walleye pollock, Theragra chalcogramma (Gershanovich et al. 1974).

Table 111.6.6 .---Volume and frequency of Pacific herring in stomachs of fur seals in the eastern Pacific Ocean, Gulf of Alaska, and Bering Sea.[1]

Area	Year	Winter				Spring				Summer				Fall			
		Volume percent	Frequency	Stomachs w/food	Stomachs empty	Volume percent	Frequency	Stomachs w/food	Stomachs empty	Volume percent	Frequency	Stomachs w/food	Stomachs empty	Volume percent	Frequency	Stomachs w/food	Stomachs
Washington	1964	-	-	-	-	0.3	1	18	6	-	-	4	-	-	-	-	-
	1967	24.2	15	89	42	6.0	2	32	68	-	-	-	-	-	-	-	-
Washington and British Columbia	1966	-	-	-	-	13.1	13	98	151	-	-	-	-	-	-	-	-
British Columbia	1958	-	-	4	9	78.9	124	251	190	-	-	9	10	-	-	-	-
	1959	-	-	16	11	29.4	55	149	185	-	-	6	2	-	-	-	-
	1960	-	-	-	-	34.9	54	136	149	-	-	-	-	-	-	-	-
	1961	88.7	30	61	55	36.5	52	'225	233	56.3	2	4	8	-	-	-	-
	1962	50.7	7	26	36	3,5	5	50	75	98.2	1	3	4	-	-	-	-
	1963	-	-	-	.	39.9	5	16	18	-	-	-	-	-	-	-	-
	1964	-	-	-	-	2.5	7	75	39	-	-	-	-	-	-	-	-
Eastern Pacific, Alaska	1962	-	-	-	-	50.4	12	29	30	0 . 4	2	287	291	-	-	15	18
Southeast Alaska	1958	99.7	33	33	30	84.1	94"	120	63	-	-	-	-	-	-	-	-
	1960	-	-	-	-	94.3	119	125	51	-	-	-	-	-	-	-	-
Gulf of Alaska	1958	-	-	-	-	1.2	5	161	346	-	-	16	50	-	-	-	-
	1959	-	-	-	-	-	-	-	-	11.5	9	43	73	-	-	-	-
	1960	-	-	-	-	-	-	1	432	297	-	-	-	-	-	-	-
	1968	-	-	-	-	-	-	77	22	3.9	3	95	133	-	-	-	-
Western Alaska	1958	-	-	-	-	-	-	-	-	-	-	52	62	-	-	-	-
	1960	-	-	-	-	-	-	-	-	0.1	1	90	73	-	-	-	-
	1962	-	-	-	-	-	-	7 . 13		0:8	2	157	163	-	-	-	-
	1968	-	-	-	-	-	-	-	-	-	-	91	42	-	-	-	-
Unimak Pass	.962	-	-	-	-	-	-	-	1	1.1	4	221	127	).6	2	70	21
Bering Sea and Unimak	.960	-	-	-	-	-	-	-	-	-	-	229	198	-	-	-	-
	.962	-	-	-	-	-	.	-	-	0.7	5	475	405	).4	2'	141	86
	.963	-	-	-	-	-	-	-	-	6.7	15	816	539	-	-	.	-
Bering Sea	.962	-	-	-	-	-	-	-	1	0	1	254	278	-	-	71	65
	.968	-	-	-	-	-	-	-	-	-	-	141	68	-	-	-	-

1/ Sources: North Pacific Fur Seal Commission 1962, 1969, 1971, 1975; Fiscus et al. 1964

Parasites and Diseases

Very little information was found regarding parasites and diseases of Pacific herring, but Arai (1969) listed the following:

Digenea:	Lecithaster gibbosus (Rud. 1802)
	Parahemiuris merus (Linton 1910)
	Pentagramma petrowi (Layman 1930)
Monogenea:	Gyrodactyloidea
Cestoda:	Phyllobothrium sp. (larval)
Nematoda:	Anisakis sp. (larval)
	Contracaecum sp. (larval)
Copepoda:	Caligus clemensi Parker and Margolis 1964
	Parabomolochus cuneatus (Fraser 1920)

Arai found 69% of Pacific herring were parasitized by L. gibbosus. A sample of 38 juvenile herring from Auke Bay, southeast Alaska, in January 1977 averaged 7 parasitic trematodes, Brachyphallus crenatus, per fish with a range of 2 to 19.[1]

Physiology

Knowledge about the physiology of Pacific herring is limited. Some of the features of salinity and temperature and their effects on herring have been discussed in the sections on Distributions, on Reproduction, and on Growth. Other information not previously noted is included here.

Evidence from literature, "according to Alderdice and Velsen (1971), suggests that eggs and larvae from North American and Asian waters can tolerate a broad range of salinities from 12-26°/oo. Asian herring develop normally at or below temperatures (4-4.7°C) that produce jaw abnormalities in British Columbia herring larvae, and maximum egg and larval survival in British Columbia is at or near 8.7°C. Details of temperature and salinity tolerance of herring eggs and larvae of various Pacific Ocean areas are presented in tabular form by Alderdice and Velsen.

Eggs from different populations have specific qualities in the low salinity range, but sexual cells are capable of fertilization at 0 to 70°/00, salinities of 7 to 40°/00 are optimal, and minimum larval mortality occurs at 10 to 36°/oo (Dushkina 1973). McMynn and Hoar (1953) found that the closure of the blastopore and the period just prior to hatching are critical , and hatching is often abnormal in salinities lower than 6°/00. Galkina (1957) stated that larvae hatched from normally developing eggs die at salinities lower than 4°/00.

Studies in the western Bering Sea indicated that fat deposits in the stomach and digestive tract of herring decrease in fall and winter (Prokhorov 1968). A significant decrease in fatness from 3.3 points in October to 1.8 points

[1] National Marine Fisheries Service, Northwest and Alaska Fisheries Center, Seattle, Wash., Monthly Report March 1977, p. 22.

in November "was assumed to be caused by a sharp reduction of feeding inten-
sity. The quantity of fat in muscles decreased from winter to spring. Fatness
of 24-30 cm length herring in October was 21-25%, but at spawning time in
May it had dropped to 6-7%.

Prokhorov also examined hemoglobin content of herring blood. He found it"
was as high as 95% during spawning migration and decreased to 75-85% during
feeding migration. During fall and winter before schools descended to the
bottom, the quantity dropped to 55.4%.

Behavior

Pacific herring are schooling fish whose behavior varies with life phase
and changes by season. It often differs by geographic. area, under varying .
hydrographic conditions, and as a response to other ecological relationships.

Schooling

Compact schools are formed in the vicinity of the spawning grounds by herring
larvae after they metamorphose and cease to be free-floating (Tester 1935,
Stevenson 1962). From spring through September-October, juvenile herring
remain in large schools feeding in inshore areas of low salinity (Rounsefell
1930a, Tester 1946, Hourston 1959, Kasahara 1961, Stevenson 1962, Taylor
1964). In late summer these schools are in deeper water and are seldom seen
during the day but come to the surface toward evening and work inshore (Thomp-
son 1917).

At the end of summer most of the juvenile herring migrate to offshore waters
(Fraser 1922, Hourston 1959), although some remain in inshore passages and
bays through the winter (Rounsefell 1930a, Kasahara 1961, Taylor 1964).
According to Hourston, juvenile herring in British Columbia are not found
again in quantity in inshore waters until they return as mature fish in
spawning stocks, but some reappear inshore in their second summer as schools
of immature fish (Tester 1935, Stevenson 1962, Taylor 1964). Tester (1946)
said that little was known of herring in their second year, but most were
believed to be on offshore feeding grounds. Rounsefell wrote that, in Alaska,
fish in their second year were extremely numerous feeding in many inlets
close inshore.

Most schools of mature herring disappear after spawning and move into deeper
water or offshore to feed, although small concentrations still occur in
inside waters in summer (Cobb 1907, Taylor 1964). In autumn or early winter
they return to inshore waters in compact schools to remain through the winter
until after spawning (Thompson 1917, Rounsefell 1930a, Stevenson 1962, Taylor
1964). Rounsefell observed that herring reappeared in early summer to feed
close to the surface in passages of southeast Alaska and Prince William
Sound. Schools of herring were caught in various parts of Chatham Strait
until August and then off Cape Ommaney at the mouth of the strait in Septem-
ber. Herring wintered in some bays of southeast Alaska where they were not
found in summer. In Prince William Sound, herring were found in western
passages in June and part of July; schools of larger herring occurred in
a few bays of the western part of the sound in late September and October.

Rounsefell also noted that herring schools may not contain fish of uniform
sizes and ages, and the degree and kind of segregation varied at different

seasons of the year. Hourston (1959) found that young British Columbia her-
ring, as they matured, joined adult schools on the spawning migration, and
Taylor (1964) said some in their second year appeared as schools of immature
fish mixing with adult stocks. Thompson (1917) determined that, in British
Columbia, mature and immature herring of all sizes were found inshore in
close proximity to each other during late autumn, but mature and immature
fish apparently segregated shortly before actual spawning because schools
on the spawning grounds were composed entirely of adult fish. Moberly and
Thorne (1974) speculated that herring in southeast Alaska segregate on win-
tering grounds into one group of ages O through 3 (juveniles) and another
group of age 3 and older (adults),

Herring schools in southeast Alaska behave differently in winter and summer
(Kolloen and Smith 1953). In winter they apparently stay close to the bottom
and generally congregate at much greater depths at certain localities until
spring. In summer the schools are constantly moving in search of food and
concentrations are not as dense as in winter. Moberly and Thorne (1974)
found wintering herring in January-February near Ketchikan were tightly
schooled during the day below 50 m and often right on the bottom with densi-
ties of about 10 fish/m^3. At night they rose toward the surface, sometimes
reaching less than 20 m, and densities were as low as 12 fish/100 m^3. Similar
behavior was noted in Bering Sea herring which in winter dropped to the
bottom during the day, began to rise at twilight, and remained at 40-60 m
from the bottom at night (Lipanov and Shestopalov 1961).

Light is a major factor in the distribution of herring larvae and it affects
vertical migrations of herring throughout their lives. Newly-hatched larvae
are attracted to both strong light (daylight) and weak light (faint light
in surface waters at night) according to Stevenson (1962). After metamor-
phosis, this behavior quickly changes and herring react negatively to light,
concentrating at the surface at dusk and remaining some distance below the
surface in daylight.

Migrations

Migrations of Asian populations are much more extensive than those of North
American populations, probably because seasonal changes in oceanography
and climate are more marked along the Asian coast than on the North American
coast (Kasahara 1961). Adult herring winter in most North American areas
in waters relatively close to the coast or in inland passages in an inactive
state during which they do little or no feeding.

Exact migration routes of herring in British Columbia, southeast Alaska,
and Prince William Sound are not known, but some theories have developed
as a result of tagging programs. In British Columbia, herring tagged in
a particular sound on the west coast of Vancouver Island tended to return
to the same sound in the next fishing season (Hart, Tester, and McHugh 1941).
Rounsefell and Dahlgren (1935) used tagging and differences in vertebral
counts and growth rates to determine a number of facts about races of herring
in 'southeast Alaska. These facts included evidence of lack of migrations
that indicated distinct races were found in several areas. Dahlgren (1936)

determined by tagging experiments that the entire spawning population of
the west coast of Baranof Island was one stock which intermingled on summer
feeding grounds. The population migrated south during the summer feeding
season to the Cape Ommaney region. In the northern Gulf of Alaska, Rounsefell
(1930a) found no well-defined migration except possibly between Shuyak Strait
(Kodiak Island Area) and Halibut Cove (Cook Inlet). Schools of herring that
were noted in Shuyak Strait in July apparently migrated to Halibut Cove
by September or October.

Herring of the eastern Bering Sea appear to undergo longer migrations, are
subject to different hydrological conditions, and behave in a slightly dif-
ferent manner than those of the Gulf of Alaska. As noted in the section
on herring distribution, the eastern Bering Sea herring winter in a rela-
tively small area in the open ocean northwest of the Pribilof Islands, al-
though other wintering areas are possible. Studies in 1961-63 showed the
herring began to gather in large, dense schools in late November-early Decem-
ber (Dudnik and Usol'tsev 1964, Shaboneev 1965). The schools carried out
distinct diurnal vertical migrations on the wintering grounds from December
to March. In December during the day they remained at the bottom or slightly
above it , principally at depths of 105-137 m from about 0600 to about 1500
hours. At dusk, they rose to midwater layers 20-50 m from the bottom in
schools 4-9 km long. Schools at night reached a height of 80 m or more from
the bottom and sometimes were found in the entire water mass from the bottom
to the surface.

Beginning in January, the vertical movements were iess intense, schools
formed a thin layer close to the bottom and only a small part rose from
the bottom. By the second half of February, concentrations were sparse,
herring were everywhere in the wintering areas in a thin layer on the bottom,
and they were more active. In March, separate schools appeared in the day-
time at some distance from the bottom, and they began leaving the wintering
grounds in March-April. Migration northeast and southeast to coastal spawning
grounds began in April-May to the end of June. In June to August, the herring
were over the shelf in small schools in surface-warmed waters, after which
they began to migrate toward the continental slope and from the surface
to the bottom, Concentrations narrowed in the end of September-October,
and commercial concentrations were found northwest of the Pribilof Islands
by the latter half of November.

No relationship was found between water temperatures and the distribution
of herring in the eastern Bering Sea, but water temperatures of the wintering
area from December to March were 2-3.5°C and were lower (0.9-2°C) in the
second half of March at the end of wintering (Dudnik and Usol'tsev 1964).
Kaganovskii (1955) believed, however, that there is a relationship of verti-
cal movements of herring to water temperatures in Far Eastern waters and,
as a rule, they avoid the thermocline. In Tatar Strait, herring stay above
the thermocline at the beginning of summer, go deeper during summer warming,
and rise to the surface again in autumn as the water cools.. .

Associations with Other Organisms

Very little is known about associations of Pacific herring with other organisms. Taylor (1970) showed in a table the numbers of tows on three cruises off British Columbia in which herring, hake, dogfish, and salmon occurred alone or in combination with one another. Herring frequently were found with dogfish, and in many instances dogfish in combination with herring and/or salmon was the dominant contributor. In another study (Hart 1943), juvenile mackerel and herring were associated to varying degrees with juvenile pilchards in British Columbia inlets, but the herring were usually smaller than the pilchards. In the eastern Bering Sea, after intensive fishing for herring, which was the principal food competitor of the walleye pollock, reduced the herring stock, the area of pollock concentration was extended and the numbers of pollock increased (Gershanovich et al, 1974). The latter authors wrote, "As a result of the present sharp decrease in herring stock, the Alaskan [walleye] pollock continues its displacement of the herring in its ecological niche as a planktophagous species."

POPULATION STRUCTURE AND DYNAMICS

Sex Ratios in the" Populations

The numbers of male and female herring in the populations are "approximately
equal, but the sexes may not be present in the same proportions in one" area
from year to year or within one year, or in adjacent areas in the same year.
Recent research on herring stocks in southeast Alaska and the Yakutat area
by Moberly (1973; 1974a,b,c) shows that in 1970-74 sampling, sex ratios in
commercial purse seine catches in southeast Alaska averaged 1:1. Ratios in
catches in variable mesh gill nets were higher (70% male, 30% female) because
the nets were selective for males when fished on the spawning grounds. In
the Yakutat area the average was 52.6% males-47.4% females in 1971 and 1973
combined sampling. Individual populations varied from 60% males-40% females
to 30% males-70% females.

Size and Age Composition

Knowledge of the size and age composition of herring in the catches is important
if researchers are to determine the causes and extent of fluctuations in
abundance of herring populations. The populations in each area are different,
however, and fluctuations also are found between years in one area.

Herring schools consist of individuals of mixed sizes and ages; the extent
and kind of segregation varies with the areas, seasons, and years. Data on
age composition, weight, length, and sex of herring from three main Alaska
fishing areas have been summarized by Reid (1971): southeast Alaska 1929-
66, Prince William Sound 1937-58, Resurrection Bay-Day Harbor (Prince William
Sound) 1941-57, and Kodiak Island 1936-59. More recent data on age, sex,
and size composition of herring from southeast Alaska and Yakutat in 1970-
74 have been compiled by Moberly (1973; 1974a,b,c). Reid warns that, 'The
possibility of a mixture of fish with different genetic or morphological
characteristics requires that considerable discretion be used in interpreting
data from a particular fishery, especially when these data are used in studying
the population dynamics of an entire district."

Size Composition

Data on average body lengths by age class of herring from various southeastern
Alaska and Gulf of Alaska reduction fisheries in 1929-66 are summarized
in Table 111.6.7. Growth curves, including the age-length relationship have
been presented previously in this herring review in the section on Growth.
Data in Table 111.6.7 indicate that average sizes of herring in the Gulf
of Alaska fishing areas vary from 12 cm at age class I to nearly 27 cm at
age class XII. The average sizes of herring in southeast Alaska are apparently
slightly larger than those of Prince William Sound and Kodiak Island. Another
point of interest is that the average size per age class has apparently decreased
as much as 1-2 cm in the areas and years listed by Reid (1971). If true,
the change would be similar to Tester's (1937) observations that herring
in two major British Columbia fisheries had decreased in size from those
taken in early years of the fisheries. Rounsefell and Dahlgren (1932) analyzed
length frequencies in one area of Prince William Sound through seven years
to illustrate how abundant size groups progress through the catch from year
to year, showing dominant year classes and growth from year to year.

Table 111.6.7.--Average body lengths of herring by age class grouped by periods, Alaska reduction fisheries, 1929-66 (from data of Reid 1971).

(N.F. indicates no fish in the age class or too few fish to supply reliable length data).

	Mean length in mm by Age Class--											
Period	1	11	111	IV	v	VI	VII	VIII	IX	X	XI	XII
Southeast Alaska[1]												
1929-39[2]	157.0	185.9	198.8	214.7	229.7	229.9	238.8	242.2	243.0	252.6	237.1	245.4
1940-49[3]	147.1	179.3	195.2	205.5	213.7	220.3	224.7	228.9	227.7	225.7	232.0	237.0
1950-59[3]	135.6	173.9	191.7	202.0	210.1	218.0	223.6	225.8	227.2	230.2	232.7	242.5
1960-66	150.7	163.1	185.2	195.5	202.4	210.0	215.7	217.8	220.5	223.4	236.2	N. f.
Prince William Sound [4]												
1937-39[5]	143.1	183.3	204.9	220.5	231.5	241.3	246.7	253.6	260.1	264.3	267.8	267.3
1940-49[5]	139.4	181.1	199.6	212.6	221.1	226.6	234.4	242.6	242.2	251.7	260.8	264.1
1950-58[5]	123.6	172.9	185.8	203.5	209.2	221.9	224.8	238.3	240.1	233.2	242.0	N. f.
Resurrection Bay-Day Harbor[6]												
1941-49[7]	136.0	178.4	198.1	207.7	220.1	223.8	228.2	23?.0	237.5	N. f.	240.2	N. f.
1950-57[7]	122.6	174.0	193.8	207.0	219.8	226.0	230.7	235.9	239.6	N. f.	238.7	252.0
Kodiak Island[8]												
1936-39[9]	129.5	173.4	203.7	220.3	232.4	239.9	244.7	251.5	258.0	261.5	265.2	269.5
1940-49[9]	142.8	182.3	204.2	218.4	227.6	235.0	241.3	246.4	249.9	256.1	257.1	257.4
1950-59[9]	122.6	162.1	186.4	192.2	208.2	218.2	225.8	237.0	243.9	241.6	256.8	260.0

[1] No length data were calculated in 1932-33, 1934-37, 1939 and 1941; the fishery did not operate in 1940 and 1942.
2/ 1934 data from Cape Ommaney only.
3/ Lengths for 1943-53 calculated from 5-mm midpoints.
4/ No length data collected in 1949 and 1953.
5/ Lengths for 1937-41, 1943-48 and 1950-52 calculated from 5-mm midpoints.
6/ No length data collected in 1943 and 1953; fishery did not operate in 1949.
7/ Lengths for 1944-47 and 1950-52 calculated from 5-Iron midpoints.
8/ No length data collected in 1936, 1941, 1952, and 1953; fishery did not operate in 1949, 1954, and 1955.
9/ Lengtha for 1937-40, 1942-48, and 1950-51 calculated from 5-mm midpoints.

Soviet scientists, in research in the eastern Bering Sea, compared the age and size composition and growth rates of herring (Rumyantsev and Darda 1970). They suggested the herring population of the eastern part of the Bering Sea shelf was of mixed composition. Size composition in 1959-61 in the wintering area northwest of the Pribilof Islands was quite variable (Dudnik and Usol'tsev 1964). Herring in catches were 12-36 cm long and from 2-12 years old, corresponding to year classes spawned in 1949-1960. In early 1961, fish caught were 22-27' cm; in the winter of 1962-63, 67 percent of the catch was of fish 23-28 cm and the range was 12-34 cm (Shaboneev 1965). In 1964, herring in catches were 8-35 cm long and weighed 30-510 g (Rumyantsev and Darda 1970). Shaboneev noted that the bulk of the population increased steadily in size in the three years 1961-63. Size compositions from the Soviet work in 1960-61 and from Japanese research in the same area in 1971 are shown in Figure 111.6.21.
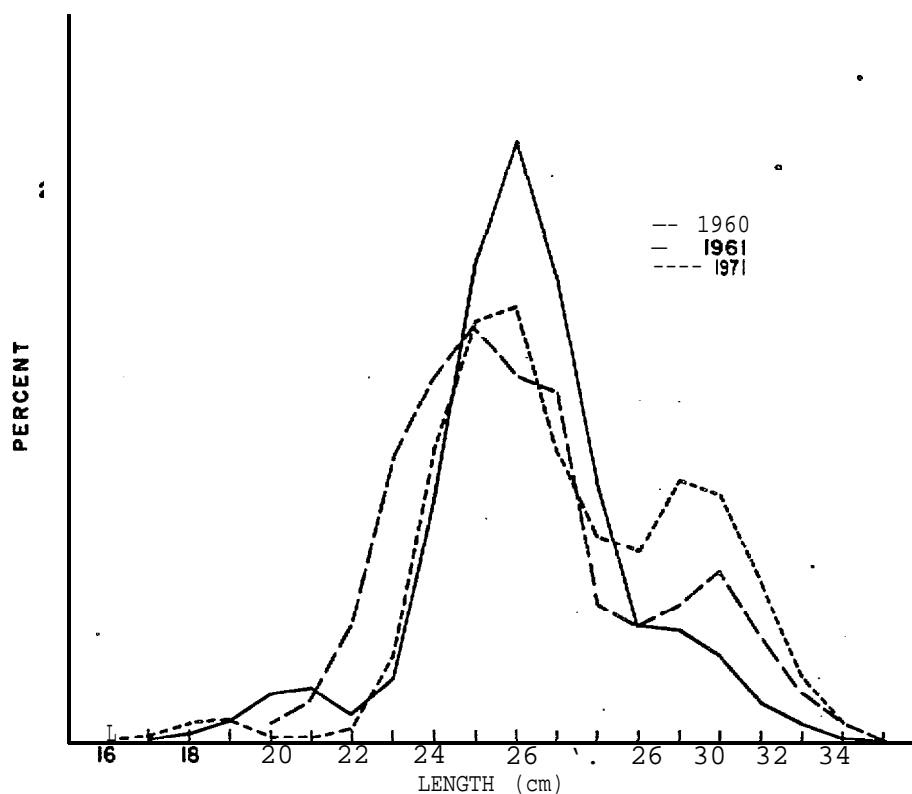
Figure 111.6.21.--Size composition of herring on wintering grounds northwest
   of the Pribilof Islands, 1960-61 and 1971 (from Dudnik and Usol'tsev 1964,
   Takahashi and Konda 1974).

Rumyantsev and Darda detailed size and weight changes of herring in the eastern
Bering Sea monthly from January to October 1964 and found significant changes
in dominant size and weight groups from one month to another. The causes
they assumed for the changes included migrations of younger fish from the
wintering. grounds and departure of mature fish for the spawning grounds.

Age Composition

The runs of herring in Alaska consist of fishes of ages I-XII, but the bulk
(75% average) are of ages III-VI (Reid 1971). in British Columbia, they are
ages I-XI, with 80-90 percent being of ages III-VI (Taylor 1955). Fish as
old as XIX have been found in herring populations in Alaska (Rounsefell 1930a),
but Reid lists very few older than age XII in the Gulf of Alaska and southeast-
ern Alaska. Fish older than age VIII are scarce in most populations of Pacific
herring in all geographic areas of their distribution (Kasahara 1961), The
average age seems to increase with latitude and is higher in the northern
part of the range. Commercial catches in both Alaska and British Columbia
consist mostly of fish in their third to sixth years, with the majority in
their third and fourth years. According to Moberly (1973), most fish in south-
eastern Alaska are mature at age IV, and that group best shows the relative
strength of each particular year class.

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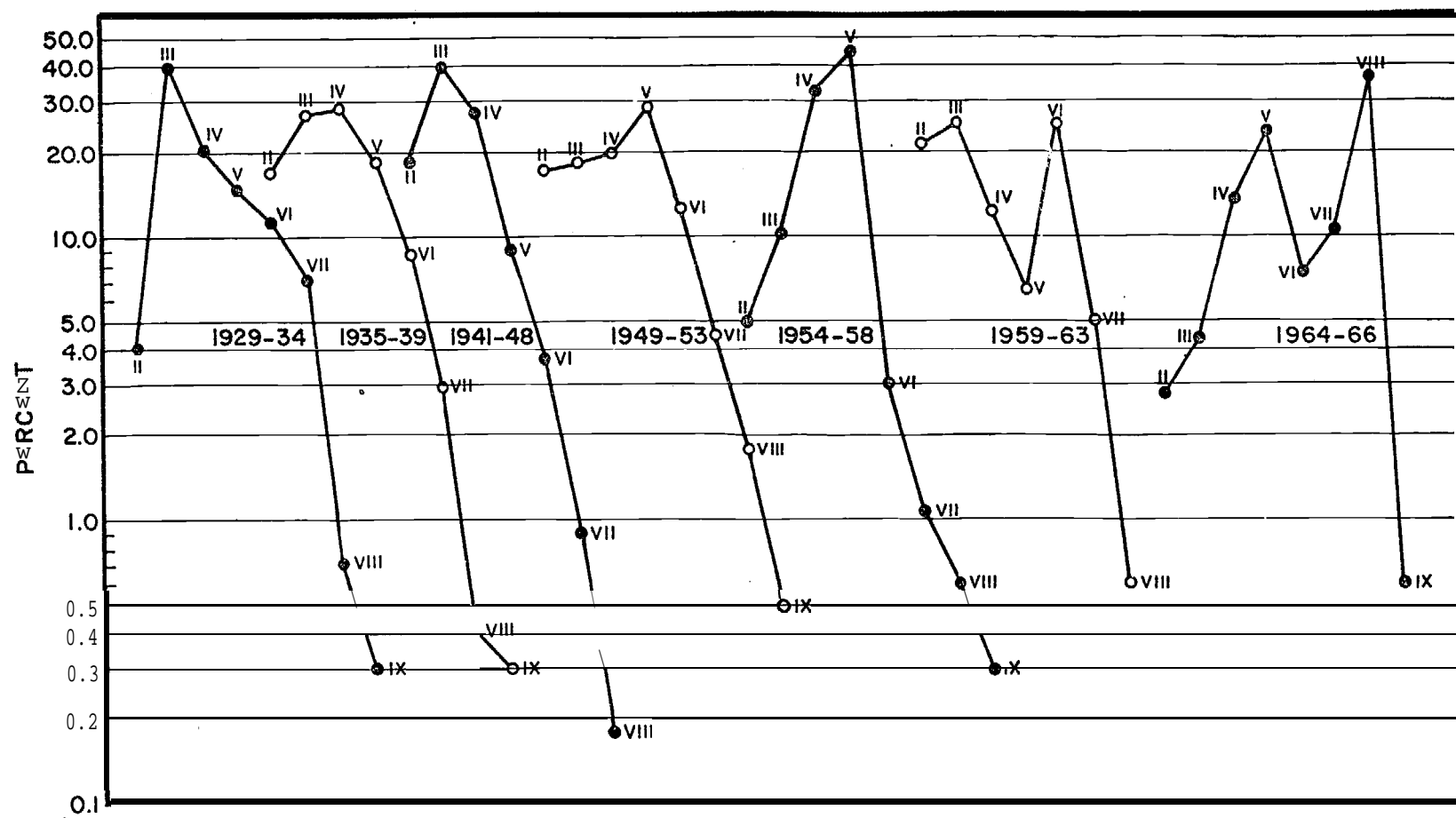
Figure 111.6.22.--Average age composition of southeastern Alaska commercial herring by period, 1929-66 (data from Hanamura 1961, Reid 1971).

Data on age composition of herring in southeastern Alaska, Yakutat, Prince
William Sound, and Kodiak Island have been compiled by various authors
(Rounsefell 1930a; Hanamura 1961; Reid 1971, 1972; Moberly 1973, 1974a,b,c).
Average age compositions for those areas by periods from 1929-74 are summa-
rized in Figures 111.6.22-111.6.25. Age composition data for the Bering
Sea for a few years have been presented by Dudnik and Usol'tsev (1964),
Shaboneev (1965), Prokhorov (1968), Rumyantsev and Darda (1970), Takahashi
and Konda (1974). and Warner and Shafford (1976). The Bering Sea data are
shown in Figure 111.6.26.
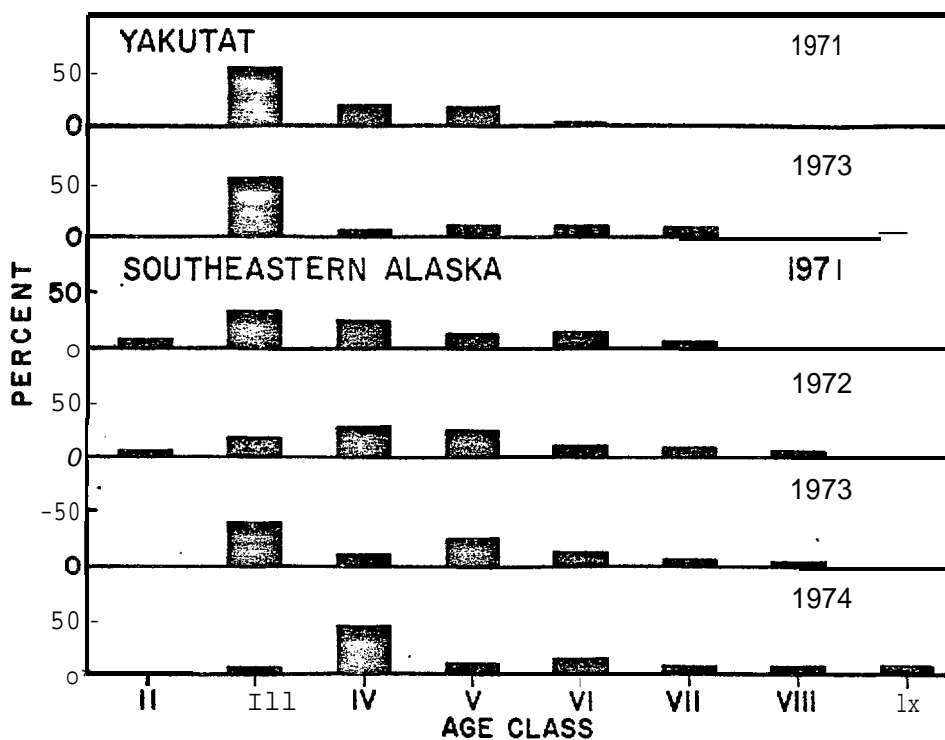
Figure 111.6.23--Percentage of herring in each age class,
'II through IX,. in the commercial fishery in Yakutat (1971,
1973) and southeastern Alaska, 1971 through 1974 (from
data of Moberly 1973; 1974a,b,c).
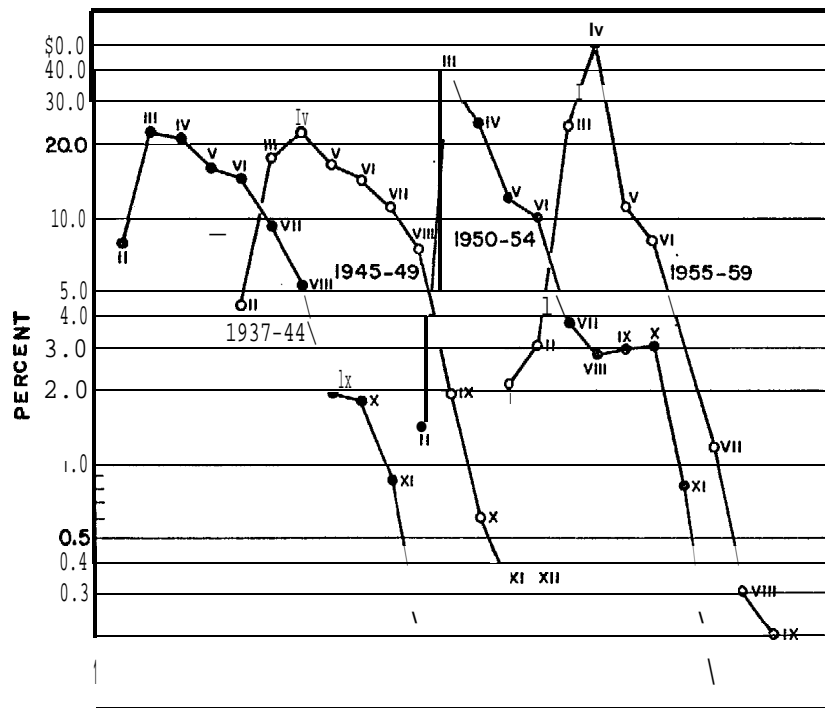
Figure 111.6.24. --Average age composition of commercial herring of the Kodiak Island area by period, 1937-59 (data from Hanamura 1961, Reid 1971).
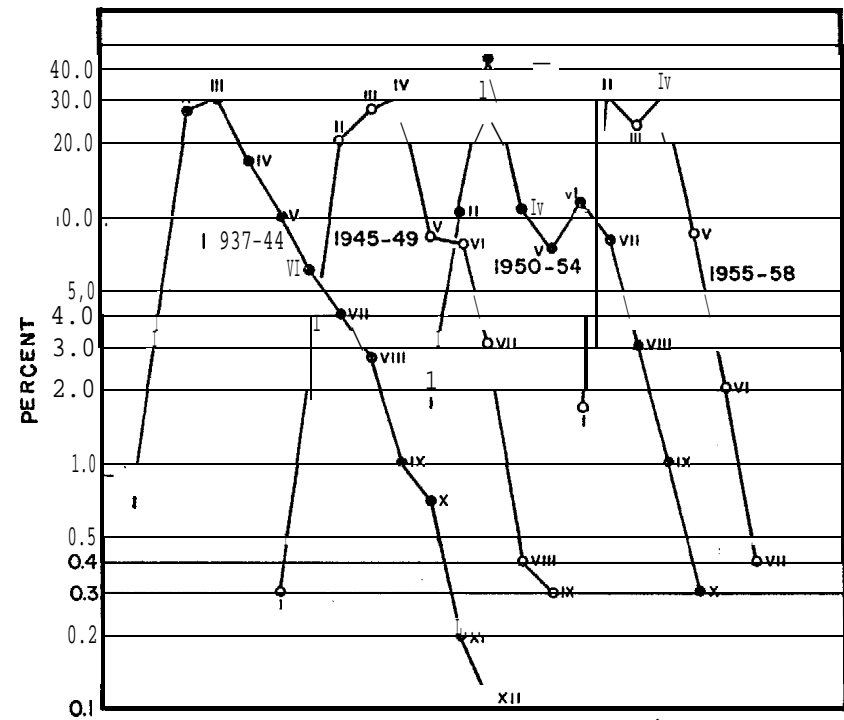
Figure 111.6.25. --Average age composition of commercial herring of Prince William Sound by period, 1937-58 (from data of Reid 1971).
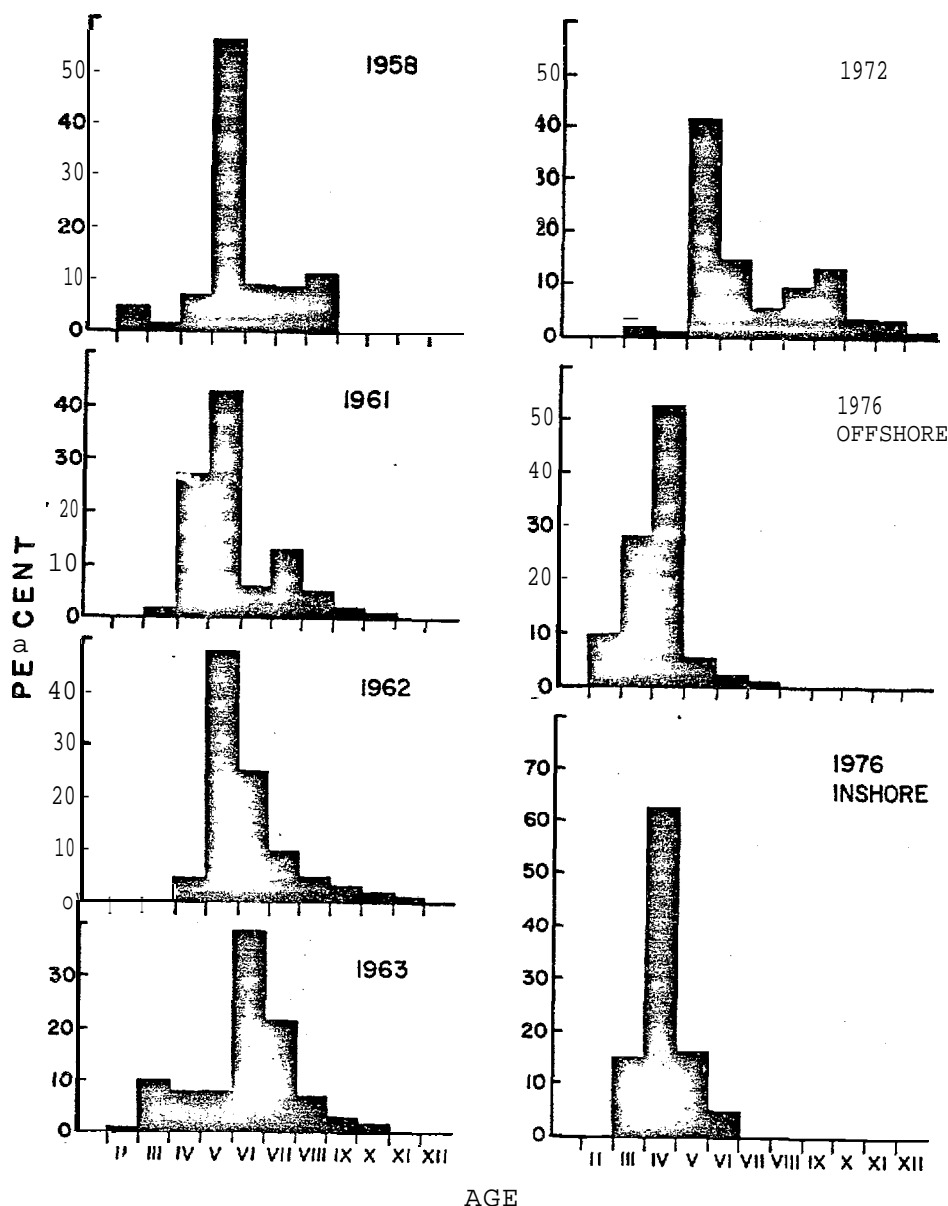
Figure 111.6.26.--Age composition of herring of the eastern
  Bering Sea, 1958, 1961-63, 1972, and 1976 (from Prokhorov
  1968, Takahashi and Konda 1974, Warner and Shafford 1976).

Dahlgren and Kolloen (1943b), reviewing age composition in the period 1929-
42 in Prince William Sound, noted two separate "runs" of herring, separated
by a period of slack fishing. Summer runs were composed mostly of younger
age groups (3- to 5-year and infrequently 6-year fish), while fall runs were
largely older individuals age 6 and older. Abundance reflected the presence
of dominant year classes, because when dominant classes were young and present
in the summer fishery, catches in summer were high. When groups were older
and entered the autumn fishery, catches in autumn were high.

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The abundance of herring in Alaska waters has fluctuated greatly, and the fluctuations have been attributed to several causes. The fluctuations are random, unpredictable, and do not seem related to the number of young produced or adults removed by fishing according to Reid (1972). Other authors state that fluctuations in Alaska and British Columbia are mainly caused by variations in the survival and strength of successive year classes contributing to the stocks (Rounsefell and Dahlgren 1932, Tester 1937, Kolloen 1947, Taylor 1955).

Dahlgren and Kolloen (1943a) theorized that fluctuations in abundance could be attributed to one or more of the following factors which they discussed:
1. Changes in the availability to the fishermen from year to year of the schools of herring at the usual fishing grounds.
2. A significant reduction in the abundance level of the species as a direct result of the removal from the stocks of the tremendous numbers of fish required to support an intensive fishery.
3. Natural fluctuations in abundance, the result of varying degrees of spawning success so that in some years a large number of recruits enter the adult stocks, in other years only a few.
4. Changes in the migration routes of the herring with the abandonment of the usual feeding grounds in favor of other grounds unknown to the fishermen.

They further commented that (1) cannot be responsible for long term fluctuations and that there is little reason to believe-that (4) abrupt changes in the migration of stocks cause declines and failures in the fishery.

Rounsefell (1934) stated that the true annual abundance of any adult herring population could only be determined by a knowledge of two things: (1) the size of annual increments to the population and (2) the total annual rate of mortality. The fluctuations in abundance, size, and quality of fish in the Prince William Sound fishery were reported caused by (1) inequality in numerical strength of annual" increments to the population proceeding from each year class and (2) insufficient numbers of older fish caused by a too intensive fishery (Rounsefell and Dahlgren 1932). Great fluctuations in abundance in Prince William Sound were caused largely by growth and passage through the commercial catch of fish of dominant year classes.

Kasahara (1961) believed that the relative abundance of herring in major spawning areas was difficult to evaluate because most northern populations were lightly exploited and great historical changes in abundance had occurred in some areas. His opinion was that available catch statistics for major herring areas of Alaska were not useful for evaluating the abundance of herring there because the stocks had never been fished intensively.

Because the total catch is related to fishery economics, to weather, and to changing fishing conditions and gear, catch statistics alone do not show true abundance. Instead, conclusions can be made about abundance of a year class and total abundance only if catches are related to the fishing effort each year a year class appears in the fishery (Rounsefell 1930a, 1931; Kolloen 1947; Reid 1972).

Hanamura (1961) analyzed the herring catch statistics and catches per boat in Alaska and made some general conclusions about the abundance in 1929-57:

    Southeastern Alaska -
        High abundance 1932-37, 1945-47, and after 1955
        Low abundance 1938-44, 1948-55
    Kodiak Island -
        High abundance 1946-50
        Period of stability, relatively high abundance 1937-45
        Low abundance 1951-57
    Prince William Sound -
        Relatively high abundance 1937-51, 1948-50, 1955-57
        Low abundance 1942-46, 1952-54.

Hanamura's paper includes graphs of catch statistics, including catch per boat for the above areas and a table listing the same data. He found that changes in stocks were not parallel between these districts and no noticeable relationships were found between the changes in various districts. A graph of theoretical abundance of the Sitka population of southeastern Alaska in 1929-46 was prepared by Kolloen (1947).

Abundance of herring in the eastern Bering Sea in 1962-63 was calculated by Shaboneev (1965) from hydroacoustic surveys of 21 wintering schools northwest of the Pribilof Islands. Various scientists had found , in Atlantic waters, average densities of from 0.03-0.05 fish/m^3 to 15-20 fish/m^3 , and in Soviet Pacific waters in Olyutorskii Bay the density was calculates as 3.38 fish/m^3. Using the Olyutorskii Bay density, Shaboneev estimated the resources in 1962-63 in the Pribilof area as 10,062 million fish, or nearly 2,160,000 metric tons (based on average weight of 215 g per fish). In the summer of 1964, the Soviets found a range of average catch per trawl of 38 to 256 fish and an average catch per drift net of 0.07 to 40.6 kg (Rumyantsev and Darda 1970). The averages for the entire investigation period were 71 fish (14.2 kg) per trawl and 4.3 kg per drift net.

Although certain biological information and detailed statistics are not available from Japanese and Soviet herring fisheries in the eastern Bering Sea, the resource shows signs of deterioration (Mason 1976):
1. Data show a downward trend in the combined catch by Japanese and Soviet trawlers during fishing years 1968-69 to 1973-74, and preliminary evidence indicates the catch remained at a low level in the 1974-75 fishing year.
2. The catch-per-unit effort (CPUE) by Japan's small stern trawlers showed a general downward trend during 1968-71 to 1971-72.
3. Japan's large stem trawlers showed a sharp drop in CPUE in the 1971-72 fishing year, and limited evidence indicates the CPUE remained at a low level in 1972-73 and 1973-74.

The catch and CPUE data for the eastern Bering Sea in 1967-68 to 1974-75 are presented in Figures 111.6.27-111.6.28.

The CPUE's for various types of gear in the Gulf of Alaska and Bering Sea based on historical data from all agencies are presented in Sect'ion IV of this report.
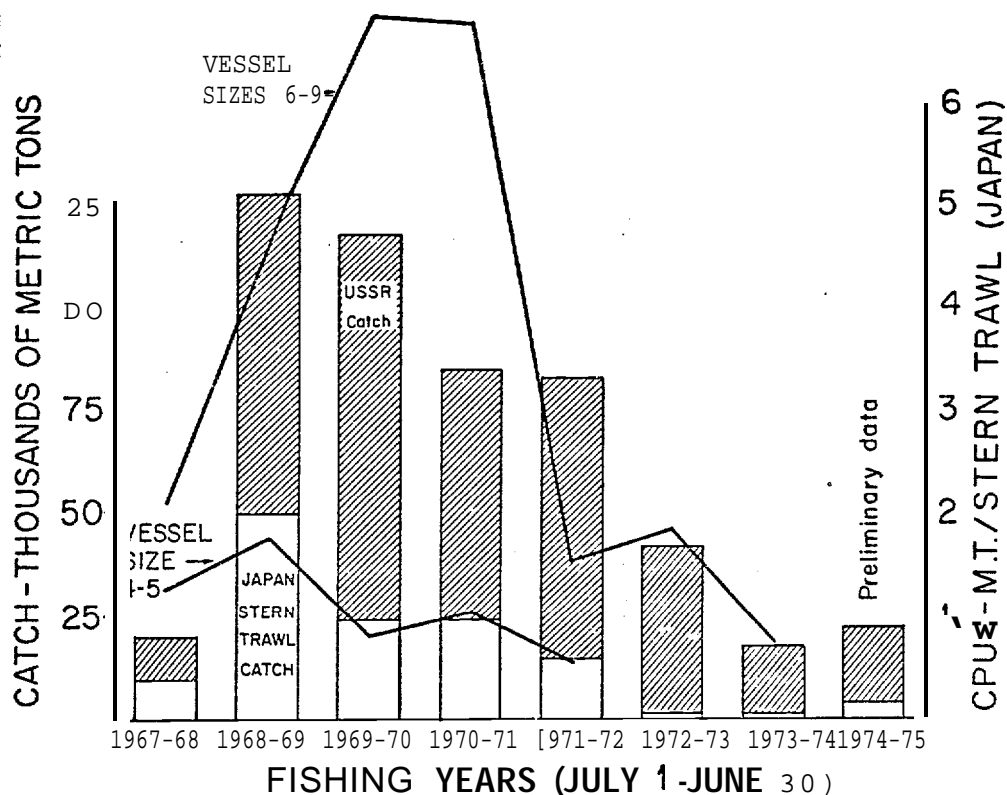
Figure 111.6.27. --Catch of herring by Japanese and Soviet trawl
fisheries east of 180° in the Bering Sea, excluding the
Aleutian area, and CPUE's for Japanese stern trawl vessels
sizes 4-5 and 6-9 (from Mason 1976).
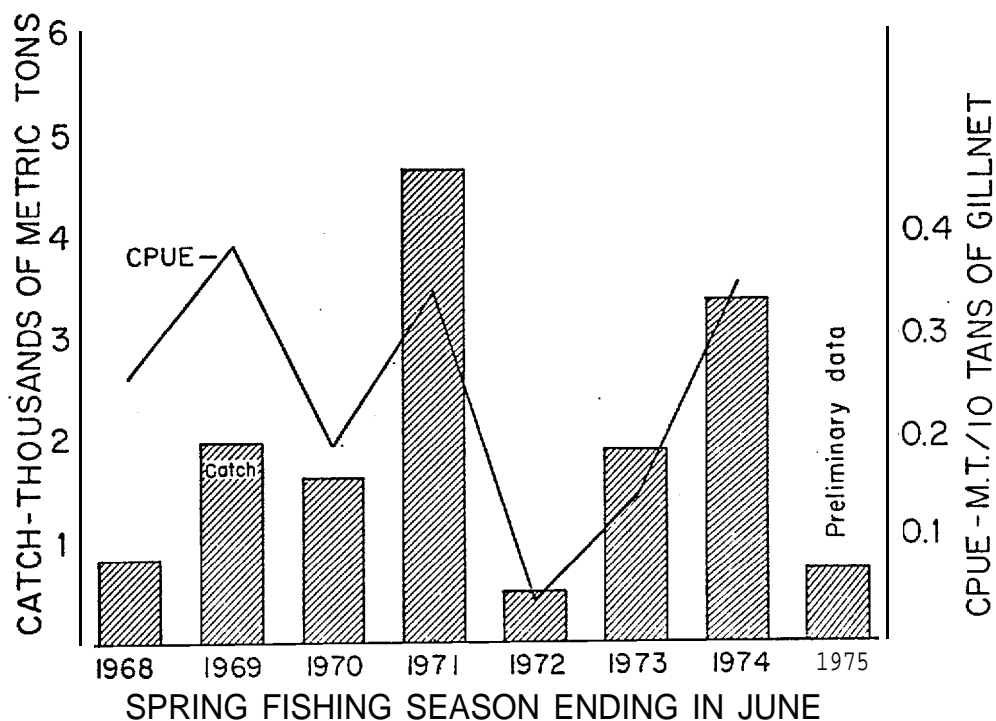
Figure 111.6.28. --Catch and CPUE for the Japanese gillnet
fishery for herring off the Bering Sea coast of Alaska
(from Mason 1976).

Recruitment

Herring populations undergo year class fluctuations that vary from area
to area, but very little is known about the causes of these variations.
The sizes of the-year classes are believed to be determined by some of
the environmental conditions and survival rates in the early period of
life (Moiseev 1956, Kasahara 1961) and do not seem to be related specifically
to the numbers of young produced or the adults, removed by fishing (Kolloen
1947, Hanamura 1961, Reid 1972). Stevenson (1962) concluded that the strength
of herring year classes in British Columbia was principally determined
by the numbers of larvae that remained in inshore waters during the critical
larval stage.

Environmental conditions affect annual spawning success and result in some
years when only a few young fish survive and other years when exceptionally
large numbers survive to form dominant year classes. The percentage of
each age group in a population thus varies from year to year with the success
of spawning and the subsequent survival. An unusually strong year class
may dominate from the time it enters the fishery at age II or III through
5 or 6 years, progressing in size because of growth, until it is no longer
found in the fishery.

Rounsefell (1930a) cautioned that a temporary decline in abundance of Alaska
herring because of the. disappearance in a catch of a dominant year class
should not be confused with a decrease caused by overfishing. He noted
that when a very dominant year class first enters the commercial catch,
the fish will be small and they will lower the average size of fish in
the catch. As the fish of the year class grow older, the average size of
the fish in the commercial catch will increase gradually until another
dominant year class appears and temporarily lowers it. Rounsefell also
stated that in nearly every case the age distributions of any two localities
differ considerably in the proportions of fish of each year class, indicating
the lack of migration between stocks of different localities.

Kolloen (1947), from continuous review of age composition, observed that,
"Over a period of years the number of herring in the catch at any age is,
within limits, in a fixed ratio to the number of that same year class that
was in the catch in the preceding year." He found that under fishing inten-
sities of the past, 4.4 times as many individuals of a year class were
caught as 4-year fish than were caught the preceding year as 3-year fish.
Further, compared with preceding years, there were only 0.7 as many 5-year
fish, 0.6 as many 6-year fish, and 0.5 as many 7- and 8-year fish. The
average rates of recruitment of a typical year class to the fishery are
given in Table 111.6.8.

Table 111.6.8.--Average rates at which a typical year class of herring will
   contribute its numbers to the fishery, based on the average rate of
   increment and decrement (from Kolloen 1947).

Age	Percentage contributed at each age	Cumulated percentage contributed at each age
3rd year	8.7	8.7
4th "	38.5	47.2
5th "	26.2	73.4
6th "	" 14.9	88.3
7th "	7.3	95.6
8th "	3.4	99.0
9th "	.8	99.8
10th " and older	.2	100.0

Herring in Alaska are recruited into the fishery generally at ages 111
and IV. According to Dahlgren and Kolloen (1943b), the greatest numbers
of each year class in the Kodiak district were available in their 4th to
7th years.

The relative change in population size from year to year is best obtained
by using the total catch and catch per unit of fishing effort (Kolloen
1947). The relationship between the number of spawning herring and the
resulting recruitment in southeastern Alaska in 1929-53 was analyzed by
comparing the catch per boat-ton-day of 3-year-old herring with the number
of fish per boat-ton-day caught three years previously (International North
Pacific Fisheries Commission 1961b). The 1929-53 brood years showed (Figure
111,6.29) a broad scattering of points with no indication of a close func-
tional relationship. The data showed, however, that with one exception
the eight years of largest recruitment at age 3 followed a brood stock
of intermediate size (between 1,400 and 3,300 in the catch per ton-day
index) .
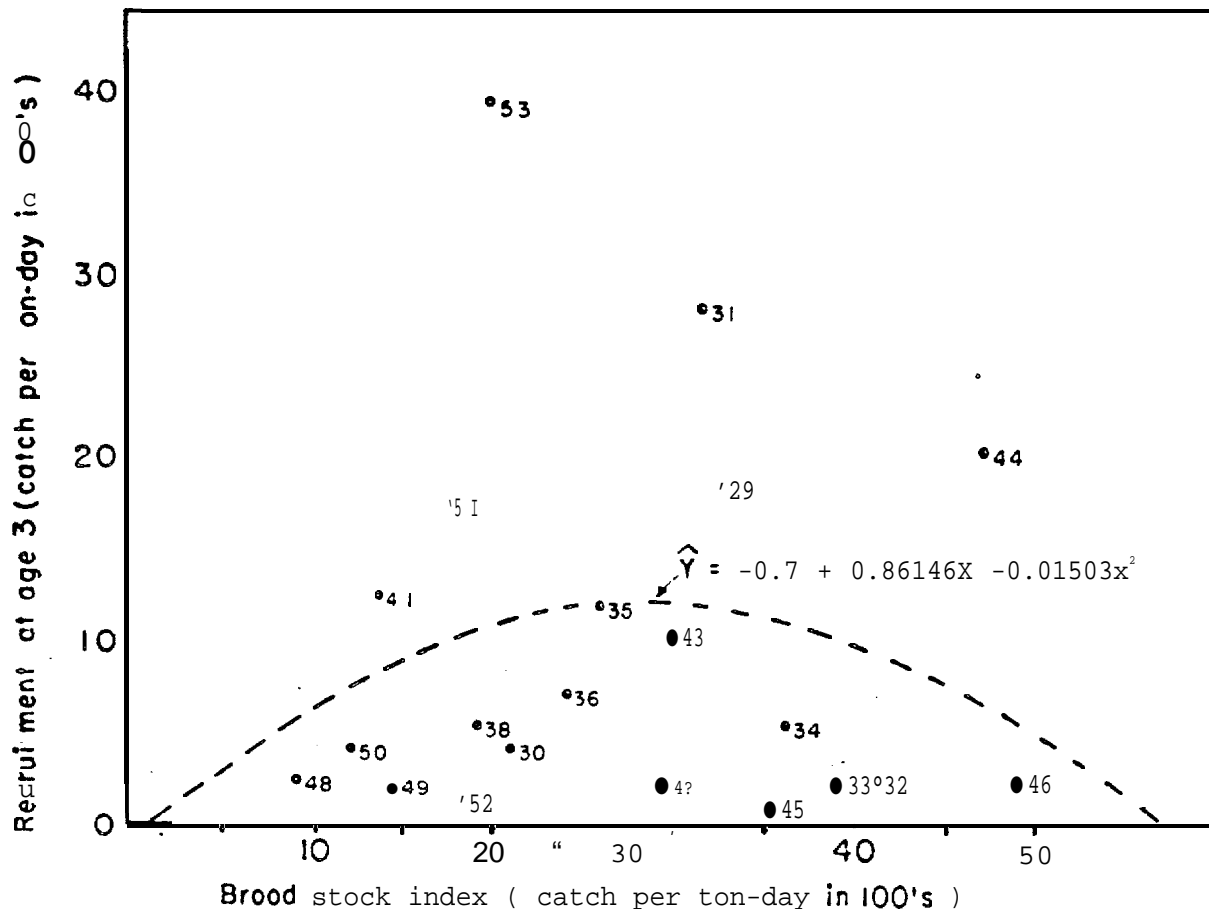
Figure 111.6.29 .--Recruitment-brood stock relationship, southeastern Alaska herring (from International North Pacific Fisheries Commission 1961b).

Dominant year classes can support the fishery in a particular district for several years, and such a dominant group may contribute as much as 90% of the total catch in a season (Dahlgren and Kolloen 1943a). For example, fish of ages 111 and IV composed about 90% of the catch in 1961 in southeast Alaska, and ages 111, IV and V totalled 97% of the catch there in 1962 (Kessler and Reid 1962, Reid 1962).

Rounsefell (1930a) stated that the presence of dominant year classes was the major factor causing fluctuations in abundance which occurred in Prince William Sound. At times when no abundant year classes of young fish are present, the fishery must be supported by a reserve of older age groups (Rounsefell and Dahlgren 1932). Fishing success in the Kodiak district over the years was considered largely dependent on only three or four abundant year classes, according to Dahlgren and Kolloen (1943b).

Dahlgren and Kolloen also determined that the abundance of the Sitka stock in southeastern Alaska deFended largely on the contributions of a single year class. The year classes of 1926, 1931, and 1935 maintained the yield of the area for many years. Dahlgren and Kolloen concluded, from a review of the year classes 1926-37, that similar dominant year classes were present in the Kodiak, Prince William Sound, and southeastern Alaska districts.
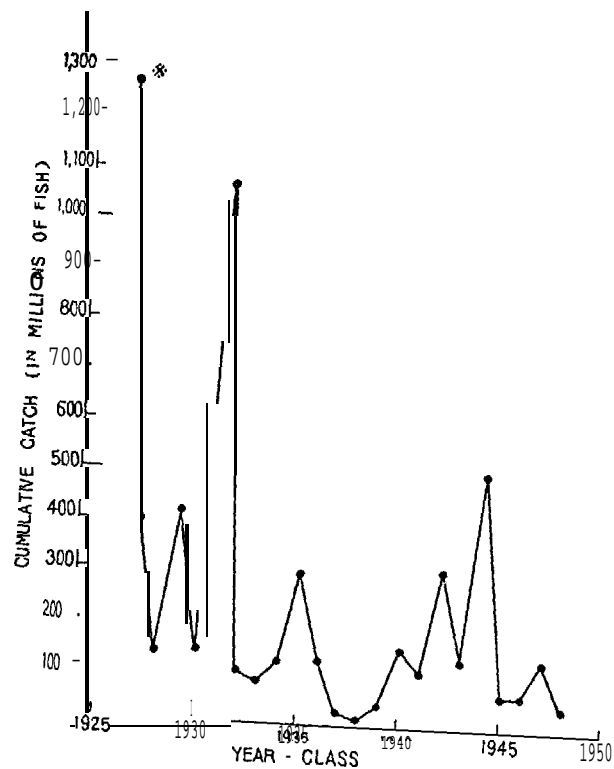
Figure 111.6.30.--Cumulative catch from each
year-class for southeastern Alaska herring
(year-classes 1926-1948). *Catches of three-
year-old fish and older (from Hanamura 1961).
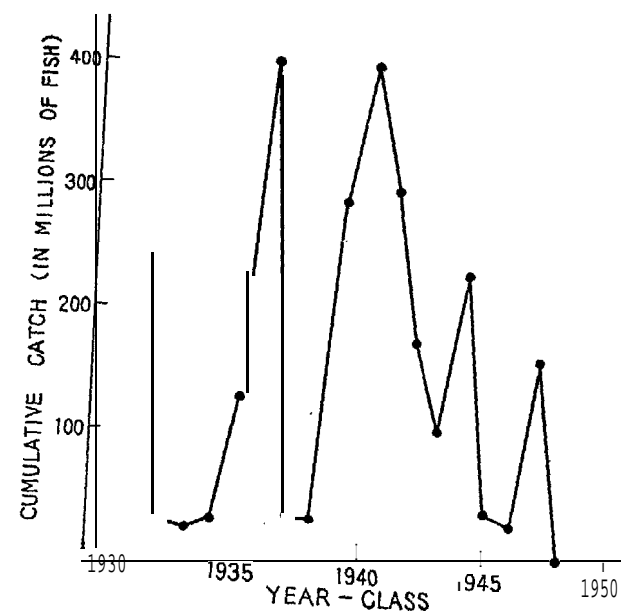
Figure 111.6.31.--cumulative catch from each
year-class for Kodiak Island herring (year-
classes 1931-1948). *Catches of six-year-
old fish and older (from Hanamura 1961).
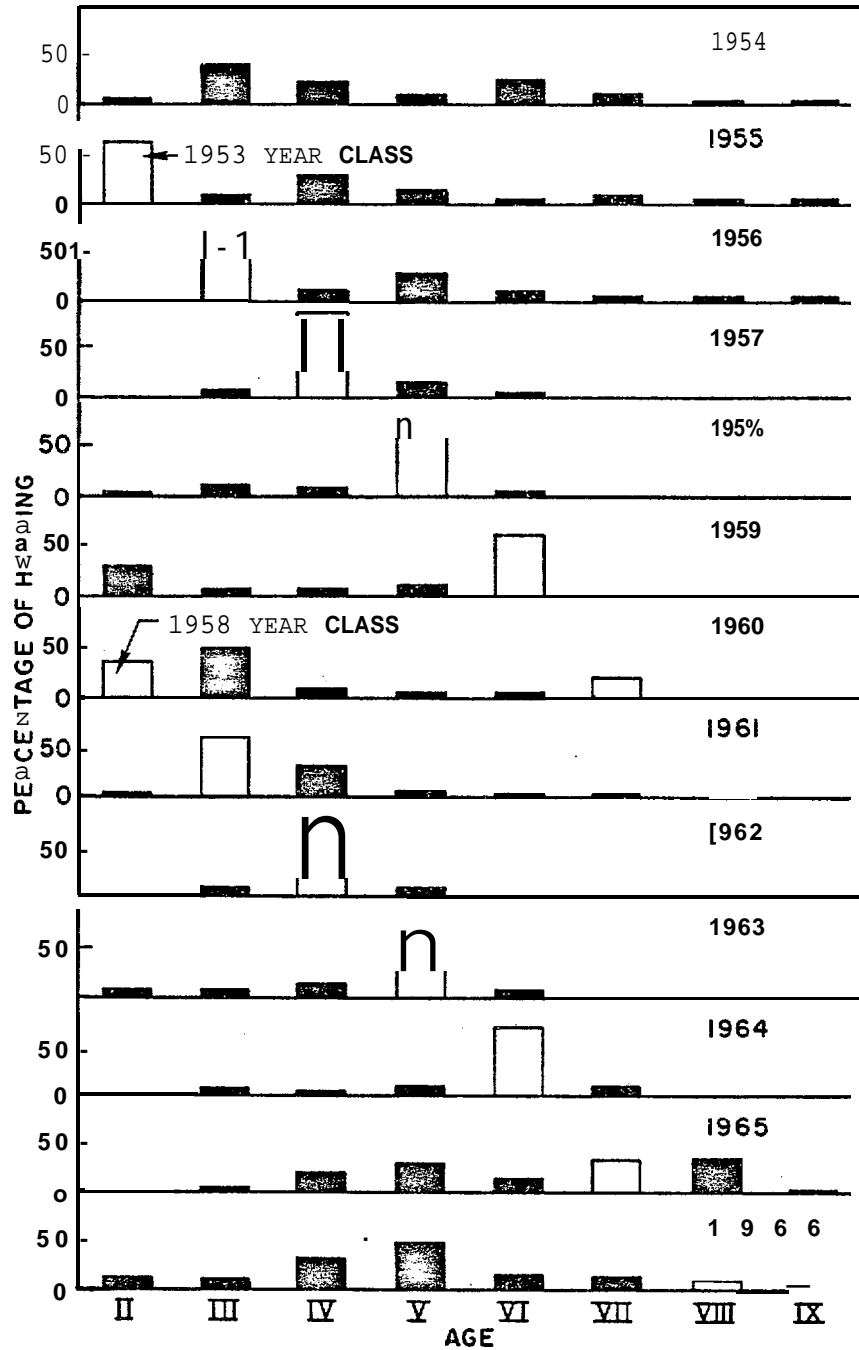
Figure III.6.32---Percentage of herring in each-age class,
II through IX, in southeastern Alaska commercial fishery
from 1954 through 1966. The white bars represent the two
major year classes, 1953 and 1958 (from Reid 1972).

Year class fluctuations for southeastern Alaska herring year classes of 1919-1957 during fishing years 1929-1957 are presented in a table in a report of the International North Pacific Fisheries Commission (1961e). Some of this information is shown graphically from analyses of Hanamura (1961) for cumulative catches of the year classes of 1926-48 of southeastern Alaska in Figure III.6.30 and for Kodiak Island in Figure 111.6.31. The percentage of each year class in the southeastern Alaska commercial fishery from 1954 through 1966 is shown in Figure III.6.32 (adapted from Reid 1972).

Briefly, from 1929-1943 the year classes 1926 and 1931 were exceptionally successful and three (1929, 1935, 1936) were fair producers in Alaska (Dahlgren and Kolloen 1943b). The remainder were mediocre or poor, and.9 out of 15 spawnings failed to provide adequate replacements to the adult stocks. The 1926 and 1931 year classes were three times as large as such year classes as 1927, 1929, 1935, 1942, and 1944 and about ten times as large as most other year classes (International North Pacific Fisheries Commission 1961d).

The year classes of 1953 and 1958 had a high survival and contributed substantially to the fisheries in southeastern Alaska in the period 1950-58, but the survival of the 1955 and 1956 year classes was much lower (Reid 1972). Favorite and McLain (1973) analyzed temperature conditions off the Queen Charlotte Islands during winter in relation to Reid's year class data and concluded that the temperature data indicated the two dominant spring spawning periods occurred following abnormally warm winter conditions (Figure 111.6.33).
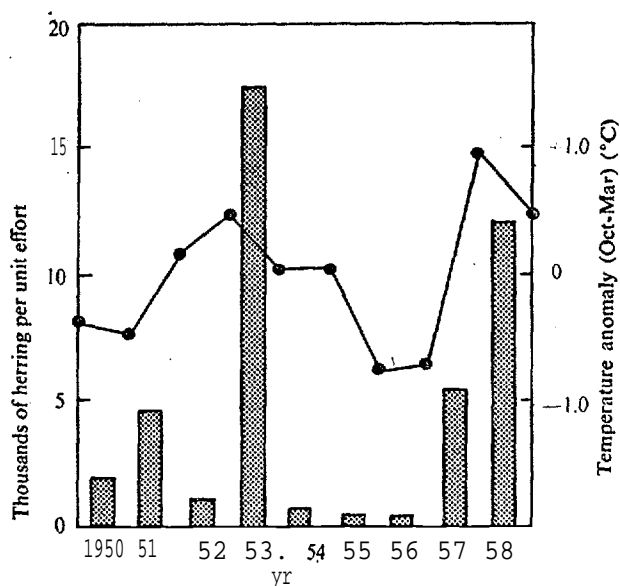
Figure 111.6.33 .--Comparison of relative abundance of year classes for herring from southeastern Alaska commercial fishery and anomalies of mean sea surface temperature (October-March) in Marsden square 157, quadrant 1 (referred to 1948-67 mean). Circles indicate temperature data (from Favorite and McLain 1973).

Mortality

Huge numbers of herring must be produced to maintain the species, because total mortality may be as high as 99.9% and only one egg in 10,000 may survive to become an adult spawning fish (Fraser 1915, Hart and Tester 1934, Outram and Humphreys 1974). Total egg mortality may be 70-80%, and average larval mortality may be more than 99% (see Table 111.6.9). The total average mortality has been estimated by Hanamura (1961) as 56% in southeastern Alaska for the years 1944-1954. Taylor (1963, 1964) estimated the total seasonal mortality in British Columbia to be 80% (range 56-99%) (see Table 111.6.9). Mortality during the juvenile stage is much less severe than in the larval stage (Taylor 1964).

Table 111.6.9 .--Mortality of eggs and larvae; average annual mortality, and total mortality of Pacific herring, British Columbia and Alaska.

Stage of Life		Percent Mortality	Area and Years	Source
Eggs	Mortality-from bird predation	39(range 30-55)	British Columbia	8
	Mortality other than from bird predation	37(range 22-50)	British Columbia	8
	Total mortality from all predation	76(range 56-99)	British Columbia	8
	Total egg mortality	70-80	USSR, British Columbia	1,5
Larvae	Average mortality	99.5(range 98.9-99.7)	British Columbia	6
	Average mortality	99+	British "Columbia	5,8
Total	Average annual total	80 (range 56-99)	British Columbia	7,8
	Average annual of 22 years	72 estimated	British Columbia years between 1937/38 and 1958/59	4
	Average annual total	56	Southeastern Alaska 1944-1954	3
	Total mortality	99.9	British Columbia	2

Sources: 1 - Galkina 1971; 2 - Hart and Tester 1934; 3 - International North Pacific Fisheries Commission 1961c; 4 - Ketchen and Taylor 1971; 5 - Outram and Humphreys 1974; 6 - Stevenson 1962; 7 - Taylor 1963; 8 - Taylor 1964

The annual natural mortality rate is more than 30-40% by age IV and is known to increase exponentially with age (Hanamura 1961). The annual rate of total mortality of herring age IV and older in the Kodiak Island and southeastern Alaska areas during 1937-1953 was between 0.4 and 0.66 as shown in Table 111.6.10.

Table III.6.10.--Average annual rates of total mortality
of Pacific herring of the Kodiak Island and southeastern
Alaska areas, age IV and older (from Hanamura 1961).

Area	Average Annual Mortality Rate	Age Groups	Period
Kodiak Island	0.40	VI and older	1937-1944
	0.50	VI and older	1945-1951
Southeastern Alaska	0.46	IV and older	1929-1934
	0.64	IV-V and older	1935-1939
	0.66	IV and older	1 9 4 1 - 1 9 4 8
	0.64	V and older	1949-1953

Using 0.46 as the base estimate for the natural mortality rate of 5-year-
old herring and an estimated yearly increase of 0.13 with the increase in
age each year, the instantaneous natural mortality rates for ages 3-8 were
obtained (International North Pacific Fisheries Commission 1961a) for southeast-
ern Alaska (Table 111.6.11).

Table 111.6.11.--Estimated instantaneous natural mortality
rates of southeastern Alaska herring according to age
(from International North Pacific"Fisheries Commission
1961a) .

Age	Instantaneous Natural Mortality Rate
3	0.20
4	0.33
5	0.46
6	0.59
7	0.72
8	0.85

No recent information was found about the fishing mortality of Pacific herring
in Alaska. United States scientists estimated an annual fishing mortality
of about 45% for herring in southeastern Alaska during 1944-54, based on
an annual average total mortality of 56% and an annual natural mortality
of about 20% (International North Pacific Fisheries Commission 1961c). Japanese
scientists, however, calculated an annual fishing mortality of 12% from the
same data (International North Pacific Fisheries Commission 1961a). The Japanese
also calculated an average instantaneous fishing mortality rate of 0.13 for
southeastern Alaska herring in the period 1952 to 1956. The instantaneous
fishing mortality rate in British Columbia was estimated as 0.57 during the
22 year period between fishing seasons 1937/38 and 1958/59 (Ketchen and Taylor
1971).

Causes of Mortality

The numerous causes of herring mortality begin to take their toll when the adult fish approach shallow waters to spawn and their dense concentrations are subjected to heavy predation from birds, fish, and mammals. Subsequent mortality to eggs, larvae, and juveniles is caused principally by various other factors.

Egg mortality

The eggs, after they are spawned, may have a total motality of approximately 70-80'% (Galkina 1971, Outram and Humphreys 1974). Initial mortality in British Columbia waters averaged about 5% for eggs attached to eel grass, presumably from infertility, overcrowding and exposure, and another 5% mortality was attributed to predation (Hart and Tester 1934).

Size of eggs, egg mass thickness, and the depth of deposition of the eggs all influence survival. Galkina (1971) found that the greater the abundance of spawning fish and the thicker the spawn, the higher the relative mortality of embryos as compared to mortality of embryos in scattered and thin spawns deposited by lesser numbers of spawners. Taylor (1971b), in laboratory experiments, attributed increased mortalities in high densities of egg deposition to respiratory difficulties in closely packed eggs, and he found hatching success decreased with the thickness of egg deposition, irrespective of depth, temperature, or salinity. Smaller eggs have a proportionally greater surface area than larger eggs, and a higher mortality noted for eggs of smaller fish could be because the eggs are more prone to desiccation when exposed to air at low tides (Jones 1972).

In British Columbia, eggs below the high tide mark were noted to suffer excessive mortality, perhaps because of low carbon dioxide or high oxygen content of the water (Tester 1942). Eggs in the intertidal zone would not be in the unfavorable environment during low tide periods when normal exchange of gases with the atmosphere would occur. Galkina (1971) found eggs deposited in the littoral zone died after the first tide, but survival in the upper sublittoral " zone was about 100%.

Wave action and storms damage eggs from exposure to sun and wind, mechanical injury by debris, and abrasion (Tester 1935, 1942; Taylor 1964; Jones 1972). Wind and wave action in one area of British Columbia caused eggs to become detached from eel grass and pile onto the beach with a resultant mortality of at least 70% (Hart and Tester 1934).

Salinity and temperature variations, which were discussed previously in relation to physiology, are potential influences on survival. Low salinity as the result of excessive fresh water is harmful in inshore waters (Tester 1942). Air-water temperature differentials affect exposed spawn (Jones 1972), and exposure of eggs from wave action and tidal ebb can result in mortality from freezing (Tester 1935).

The greatest loss of herring eggs comes as a result of predation by birds such as seagulls, ducks, and crows; other predators cause less mortality (Cleaver and Franett, no date; Tester 1935). Mortality of herring eggs caused

by scoters and **scaups** at three- stations in **Puget** Sound, Washington", waters
ranged from 39.1 to 99.6% according to Cleaver and **Franett.** In research by
Taylor (1964) in British Columbia, birds were estimated to cause an egg loss
of 39% (range 30-55%), mortality other than from bird predation was 37% (range
22-50%) and total mortality from all predation "was 76% (range 56-99%).

Larval Mortality

The **early** larval stage is a critical period **in** survival which is related
to the degree of dispersion from the spawning locality; the greater the disper-
sion the less the survival (Taylor 1955). As the larvae are carried passively
by currents from inshore waters to the open sea, **they** are subject to a mortal-
ity estimated to be as much as more than 99% (Taylor 1964). Although this
mortality is possibly related to their exposure to predation, starvation,
temperature and salinity conditions, those factors separately or together
apparently are not as important as the transport from the hatching area to
the more unprotected open sea (Tester 1935, **Stevenson 1962,** Taylor 1964).

During this period of transport, the newly hatched larvae **lack** energy reserves
after absorbing the yolk sac, and large numbers die from lack of food when
the embryonic supply is used and they must start to feed (Tester 1935, **Dement'eva**
1968). Taylor (1964) considered the **lack** of the right kind of food in areas
to which larvae were transported **to** be a major cause of mortality.

Although temperature and salinity were not considered important mortality
factors in inshore areas, the great mortality of **larvae** offshore was suggested
as possibly connected to the high salinity of the open sea (Stevenson 1962).

The various predators of all stages of herring have been discussed previously
in the section on herring Predators and Competitors and in Table 111.6.5.
As noted previously, predation on larvae was found in British Columbia to
total only a small part of the possible 99+% total larval mortality (Stevenson
2962) .

FISHING "

History of the Fishery

The coastal natives of Alaska captured herring for food for hundreds of
years, but large-scale commercial fishing for herring did not arrive until
the late 19th century. According to Cobb (1906), individuals in Wrangell,
southeast Alaska, were engaged as early as 1878 in catching herring, extracting
oil, and salting and drying the fish. Also, a company at St. Paul, Kodiak
Island, put up 500 boxes of smoked herring and 25 one-quarter barrels of
salted herring in 1880. Commercial herring fishing in Alaska is generally
considered, however, as beginning in 1882 with the establishment of an oil
and fertilizer plant at Killisnoo in southeastern Alaska (Rounsefell 1930a).

The herring fishery in central Alaska commenced more than thirty years after"
starting in southeastern Alaska. The Prince William Sound fishery originated
in 1913, but intensive fishing there dates from 1918. Gillnet fishing started
in Cook Inlet in 1914, and purse seining began there in 1923. On Kodiak
Island, a small fishery was conducted in the vicinity of Kodiak by 1916.
The fishery in western Alaska was established on Simeonof Island (Shumagin
group) in 1906 and at Chignik on the Alaska Peninsula about the same time.

In the Bering Sea, a small commercial fishery with drag seines was begun
in 1909 at Golovnin Bay in Norton Sound and was carried out until sometime
before 1945 (Rounsefell 1930a, Rumyantsev and Darda 1970). Fishing was begun
again at Golovnin and Norton Bays in 1977. No commercial fishery existed
in the Aleutian Islands area until 1928 when a summer herring fishery with
purse seines developed at Unalaska Island in the Dutch Harbor area and contin-
ued until 1945. Commercial fishing for whole herring has been done annually
in the Togiak region of Bristol Bay since 1967, except in 1971 and 1976
when operations were curtailed because of low prices (Westpestad 1977, citing
personal communication from Ron Regnart).[2/]

Foreign nations began fishing for herring in the eastern Bering Sea and
Gulf of Alaska in the 1960's. Soviet exploratory vessels reported herring
in the eastern Bering Sea in 1957, and the Soviets sent Bering Sea expeditions
in subsequent years (1958-64) to gather biological and fishery data (Shaboneev
1965). First commercial catches were 9,800 metric tons in the winter 1960-
spring 1961 season in the herring wintering grounds northwest of the Pribilof
Islands. Large fleets of 100 to 150 Soviet trawlers and support ships fished
at the height of the fishery in 1964 and 1965, but the fishery diminished
in 1966 (Chitwood 1969).

The Japanese developed herring fisheries in the eastern Bering Sea about
1962 with small catches reported. Their trawl fleets started fishing the
eastern Bering Sea in 1964 with little success, but made catches of more
than 10,000 m t annually from 1968 to 1971 (Takahashi 1975). The 'Japanese
also began fishing herring in the same area with gillnets in 1968. According
to Mason (1976), the Republic of Korea conducted a minor trawl fishery for
herring off the Bering Sea coast of Alaska in 1974.

[2/] Westpestad, V. G. 1977. Status of the Pacific--herring fisheries and
resource of the eastern Bering Sea. Natl. Mar. Fish. Serv., Northwest and
Alaska Fish. Center, Seattle, Wash, 16 p. (Processed.)

Until herring stocks off the coast of Alaska were removed in 1959 from absten-
tion under the International Convention for the High Seas Fisheries of the
North Pacific, Japan, by agreement, was not allowed to fish for herring
in the Gulf of Alaska. In 1963, the Japanese fished for herring around Kodiak
Island but the catch was small and the fishery did not continue.[3/]

Since the inception of the herring fishery in Alaska, four types of industry
have been carried out -- the manufacture of oil and fish meal, salting and
pickling of fish, preparation of whole fish for bait, and the processing
of roe (Rounsefell 1930a, Reid 1972). The reduction fishery for production
of oil, fertilizer, and fish meal was an important industry from 1882 until
1966. Following World War I, the reduction industry expanded greatly.
In 1927 there were 25 reduction plants -- 18 in southeastern Alaska and
7 in Prince William Sound according to Rounsefell. More than 90% of all
herring caught from 1929 to 1966 were processed for animal food or fertilizer
or into oil for paints and industrial uses (Reid 1971). The maximum production
of herring oil and meal was in 1937 with the processing of 251 million lb
(113,853 mt) by 72 boats and 17 plants (Reid 1972). The reduction industry
declined after 1937 because of decreased demand and prices, resulting in
operations being discontinued in Prince William Sound in 1958, the last
year in Kodiak was 1959, and the industry in southeastern Alaska ended in
1966 (Reid 1972).

The pickling industry was initiated in Alaska about 1900 at Petersburg.
The U.S. Bureau of Commercial Fisheries introduced the Scotch method of
curing herring in 1917 , and this quickly replaced the Norwegian method of
hard curing (Rounsefell 1930a). Several large salteries were built in Chatham
Strait and Prince William Sound in 1918, establishing the herring fishery
as a permanent Alaska industry. During most of the years from 1912 to 1922
the bulk of the catch was salted or canned, but after 1922 the production
of salted herring generally declined and ceased in 1954 (Reid 1972).

The bait industry had become an important Alaska industry by 1912 or 1913
after working north up the Pacific coast (Rounsefell 1930a). In 1927 the
halibut industry used more than 8 million lb (3,629 mt) of herring bait
from Alaska. The bait industry has continued until the present with fluctu-
ations caused by demand. A high demand for bait herring in recent years
resulted in an average catch of nearly 6 million lb (2,679 mt) per year
during 1965 to 1973.

The commercial fishery for herring roe and eggs on kelp developed in the
1960's as a result of a demand and growing market for two types of products
that are considered delicacies in Japan. The herring roe is removed from
mature herring and salted or frozen. Kelp on which herring eggs have been
spawned is harvested and usually processed by salting. Roe herring and eggs
on kelp now compose the bulk of landings in Alaska. Alaska Department of
Fish and Game (1974) statistics show that the production of cured roe in
1974 was almost 4.5 million lb (3,030 mt) and eggs on kelp totalled nearly
1.1 million lb (498 ret).

3/ Forrester, C. R., A. J. Beardsley, and Y. Takahashi. MS 1974. Groundfish,
shrimp, and herring fisheries in the Bering Sea and northeast Pacific--histor-
ical catch statistics through 1970. Int. North Pac. Fish. Comm. , Bull.

Fishing methods, vessels, and gear have changed and have become more efficient since the beginning of the industry. Early fishing methods are reviewed by Rounsefell (1931). The first fisheries in southeast Alaska used Norwegian seines and oar-propelled seine boats. Purse seines from power boats, introduced shortly after 1900, replaced the Norwegian-type seine by 1927. In the early days gillnets were used mainly by salmon trollers to catch bait herring. Sizes of boats increased from an average of 23 net tons in 1922 to an average of 34 net tons in 1929. By 1929, boats of 35 and more net tens included 50 percent of the fleet. Purse seines also changed in length and depth, gradually increasing from 170 fathoms (311 m) to over 200 fathoms (366 m). In present fisheries, purse seine gear is most common, some seines being as large as 25 fathoms (46 m) deep, 250 fathoms (460 m) long, and capable of taking as many as 700,000-900,000 fish (about 100 mt) in a single set (Reid 1972).

Other developments have included echo sounders to locate schools of fish in the 1940's, powered seine hauling blocks developed in the 1950's, and the use of lights to attract herring in the 1960's (Outram and Humphreys 1974).

Soviet and Japanese fleets take the bulk of their catches in trawl nets. Both nations use various types of trawlers that usually work in conjunction with factory ships and support ships. The Japanese trawlers include small side trawlers (100-170 feet long), pair trawlers (90-150 ft), and stem trawlers" (Chitwood 1969, Dickinson 1973). The stem trawlers are of four types: smaller 300 ton (average 140-165 ft), 500 gross-ton class (170-190 ft), 1500 gross-ton class (230-270 ft), and large factory stern trawlers (290-370 ft). Japanese trawl fleets may fish for various species of fish and may include as many as 135 trawlers and 5 factory ships.

The Soviet trawlers most commonly used are the SRT (medium fishing trawler) that is 125 feet long (Chitwood 1969). Other Soviet trawlers include the SRTR (refrigerated medium fishing trawler, 167 ft), the SRTM (medium freezer fishing trawler, 178 ft), and the BMRT (large freezer fishing trawler or factory trawler, 278 ft). In the early years of the eastern Bering Sea fishery, the Soviets fished herring with the 27 meter trawl used to catch ocean perch (Lipanov and Shestopalov 1961). The Soviet fleets vary in size but in 1960-62 were composed of about 50 side trawlers and support ships, and nearly doubled in 1963 to include about 100 trawlers plus support ships, according to Chitwood.

In addition to trawlers, the Japanese in the eastern Bering Sea employ gillnet fishing vessels 80-90 ft long fishing a gillnet shorter than the 9-mile type used for salmon. It is about 18-20 ft (5.'5-6 m) deep with 2-inch (5 cm) stretch mesh web, and it is anchored and submerged (Dickinson 1973). The Japanese also have caught some herring in Danish seines. Gillnets also were used in United States fisheries in the Aleutian area (Scheffer 1959) and some are now employed in the eastern Bering Sea coastal fishery. In the United States commercial bait fishery in Alaska, fish are captured during the spring spawning season in round-haul seines or traps and held alive in enclosures ("pounds") until they can be processed (Reid 1972). Since 1976 gillnets, seines, and pounds have been used in southeastern Alaska (Blankenbeckler 1976).
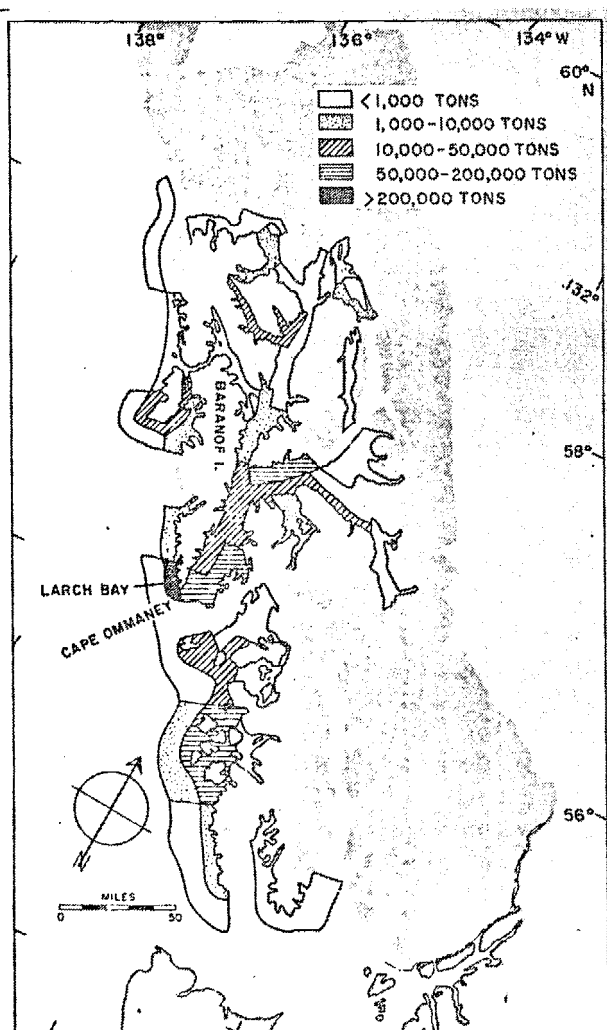
Figure 111.6.34. --Distribution of herring catches in southeastern Alaska, 1929-66 (from Reid 1971).
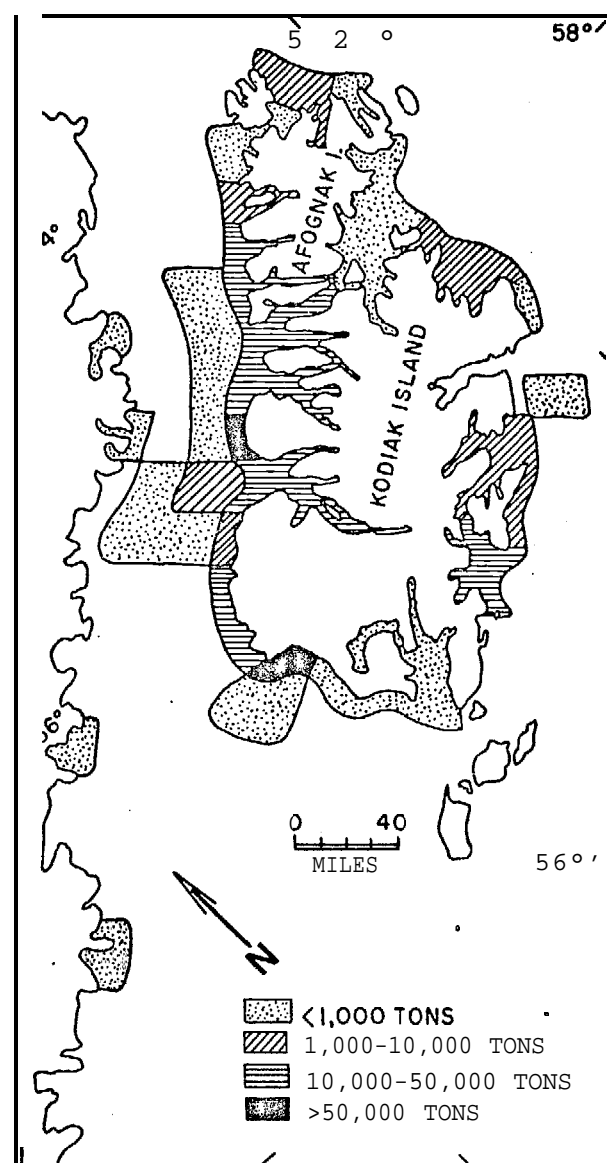
Figure 111.6.35. --Distribution of herring catches at Kodiak, 1936-1959 (from Reid 1971).

Catches

The Alaska herring fishery is carried out primarily in inshore channels and bays in June to September, but a winter fishery began in 1974 in southeastern Alaska. In the eastern Bering Sea, both a winter fishery offshore and a spring-summer fishery inshore have been conducted in recent years.

The three major Alaskan herring fishing districts and the historic geographical distribution of catches are shown in Figures 111.6.34-111.6.36. Herring catches by specific statistical areas within the three fishing districts (southeastern Alaska 1929-56, Prince William Sound 1937-56, and Kodiak 1937-.56) have been listed by Skud, Sakuda, and Reid (1960).

In 1882, the first year of the commercial fisheries in Alaska, 3 million . lb (1,361 mt) were taken, and by 1887 the catch reached 22.2 million lb (10,070 mt). Catches subsequently decreased and did not reach the same level until 1911 when the catch totalled 24.3 million lb (11,022 ret). The demand for food in World War I caused an increase in catch and an expansion of the industry. The catch in 1922 was 83.1 million lb (37,694 ret), in 1930 it was nearly 189 million lb (85,640 ret), and the record catch was 261.4 million lb (118,571 mt) in 1937. After 1937 the catches declined greatly, exceeding 200 million lb (90,720 mt) only in 1938, 1939, and 1946 (Anderson and Power 1957).
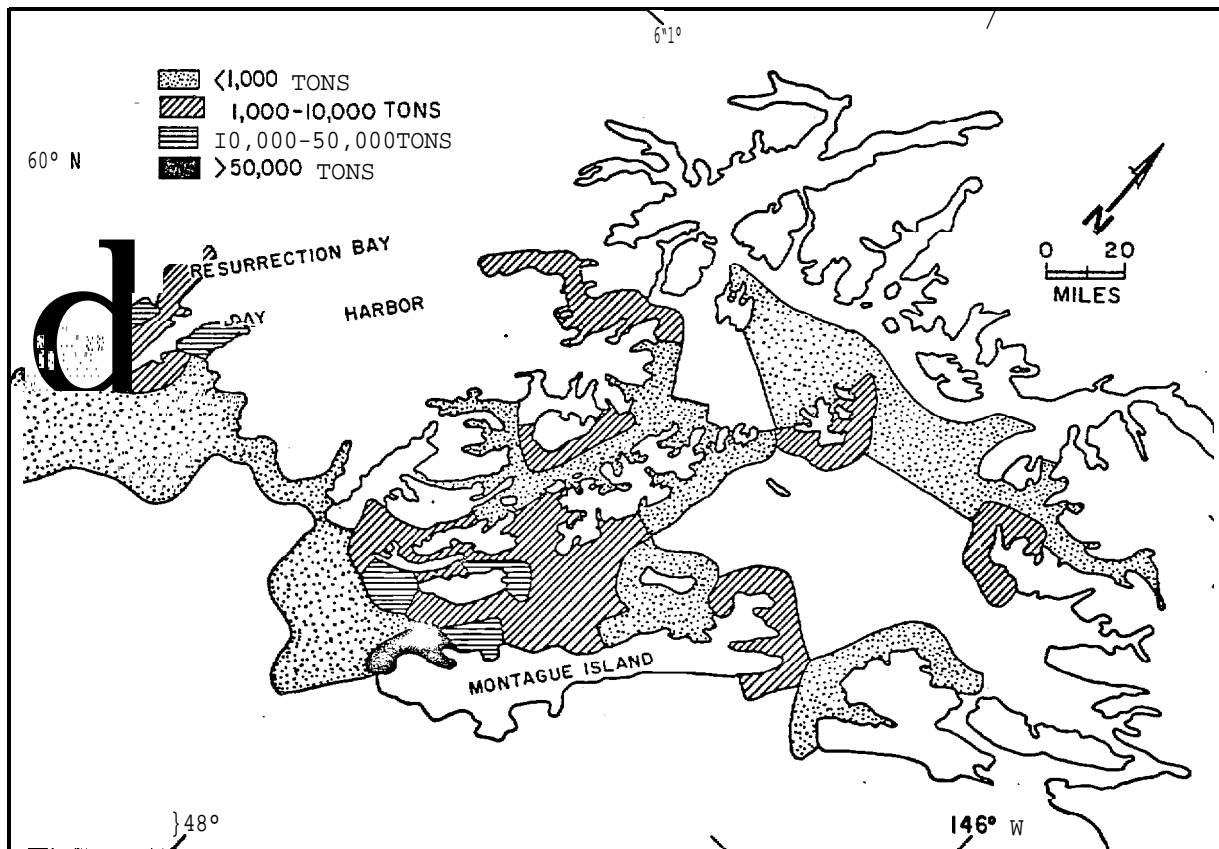
Figure 111.6.36 .--Distribution of herring catches in Prince William Sound (including Resurrection Bay and Day Harbor) , 1937-58 (from Reid 1971).

Table 111.6.12.--Catch of Pacific herring in Alaska by district, 1882-1975 (in millions of pounds).

Year	South-eastern	Central	Western	Total	Year	South-eastern	Central	Western	Total
1882	a/	a/	a/	3.0	1931	96.3	17.9	5.3	119.5
1883	a/	a/	a/	8.4	1932	105.1	40.1	3.6	148.8
1884	a/	a/	a/	13.2	1933	127.1	42.0	3.5	172.6
1885	a/	a/	a/	17.0	1934	138.8	60.2	4.3	203.3
1886	a/	a/	a/	22.0	1935	122.0	96.3	7.5	225.8
1887	a/	a/	a/	22.2	1936	79.1	126.2	3.8	209.1
1888	a/	a/	a/	6.0	1937	105.9	155.4	·0.1	261.4
1889	a/	a/	a/	10.5	1938	50.8	178.8"	1.4	231.0
1890	a/	a/	a/	10.5	1939	45.4	182.9	1.4	229.7
1891	a/	a/	a/	17.6	1940	6.2	103.9	1.3	111.4
1892	a/	a/	a/	18.7	1941	10.2	145.5	0.5	156.2
1893	a/	a/	a/	14.4	1942	7.4	38.6		46.0
1894	a/	a/	a/	15.3	1943	18.7	71.6		90.3
1895	a/	a/	a/	6.5	1944	38.8	100.3		139.1
1896	a/	a/	a/	5.6	1945	54.8	97.7	0.2	152.7
1897	a/	a/	a/	7.1	1946	81.1	136.0	0.1	217.2
1898	a/	a/	a/	9.0	1947	89.2	106.1		195.3
1899	a/	a/	a/	8.1	1948	37.4	133.6		171.0
1900	a/	a/	a/	13.0	1949	34.9	0.3		35.2
1901	a/	a/	a/	14.6	1950	31.4	137.0		168.4
1902	a/	a/	a/	9.5	1951	28.0	60.2		88.2
1903	a/	a/	a/	13.7	1952	36.2	9.3		45.5
1904	a/	a/	a/	16.0	1953	30.8	1.6		32.4
1905	a/	a/	a/	15.1	1954	16.4	18.9		35.3
1906	a/	a/	a/	10.2	1955	29.0	35.2		64.2
1907	0.7	2.6	6.4	9.7	1956	50.0	57.4		107.4
1908	0.8	2.0	9.4	12.2	1957	49.5	68.8		118.3
1909	0.9	2.1	13.5	16.5	1958	77.6	11.2		88.8
1910	13.6	0.1	-	13.7	1959	99.9	7.7		107.6
1911	24.1	0.2	-	24.3	1960	77.8	*		77.9
1912	32.1	-	-	32.1	1961	48.2	*		48.3
1913	27.0	-	-	27.0	1962	33.9	k		33.9
1914	16.6	0.3	-	16.9	1963	31.2	*		31.2
1915	13.9	-	-	13.9	1964	46.7	1.2		47.9
1916	22.4	0.3	-	22.7	1965	24.3	1.3		25.6
1917	24.8	2.7	-	27.5	1966	13.7	5.5		19.2
1918	35.6	12.1	-	47.7	1967	5.6	5.2	0.2	11.0
1919	22.0	16.0	-	38.0	1968	3.9	4.0	0.2	8.1
1920	32.9	21.5	-	54.4	1969	7.3	5.7	0.1	13.1
1921	12.0	25.7	-	37.7	1970	6.6	0.7	0.1	7.4
1922	34.0	48.4	0.1	82.5	1971	6.0	4.1		10.1
1923	42.4	43.3	0.1	85.8	1972	9.9	4.0	*	14.0
1924	58.7	41.7	0.2	100.6	1973	15.9	18.9	*	34.9
1925	115.6	66.4	0.1	182.1	1974	18.9"	19.9	*	38.9
1926	147.7	30.7	0.2	178.6	1975	14.9b/	20.4b/	0.1b/	35.4b/
1927	105.6	21.9	0.2	127.7					
1928	130.5	22.3	10.3	163.1					
1929	165.9	11.9	8.2	186.0					
1930	150.9	31.4	6.5	188.8					

a/ Data not available, b/ Preliminary (ta.*Catch less than 100,000 lb.
Sources: 1882-1955 from Anderson and Power'(1957); 1956-1969 from International North Pacific Fisheries Commission, Statistical Yearbooks 1956-1969; 1970-74 from Alaska Dep. of Fish and Game, Stat. Leafl. 21, 23, 25, 26, 27; 1975 preliminary data from Alaska Dep. of Fish and Game.

Since 1946, the catches have fluctuated considerably. A catch of 107.6 million
lb (48,807 mt) in 1959 was the last that exceeded 100 million lb, and the
7.4 million lb (3,357 mt) in 1970 was the lowest catch in the fishery since
1897. The trend since 1970 has been continually upward because of the devel-
opment of the roe and bait fisheries. Total catches of the United States
fishery from 1882 to 1975 are presented in Table 111,6.12.

The catches of United States fishermen in the Bering Sea have been included
in the total catch statistics in Table 111.6.12. As a matter of interest,
however, American"herring catches specific to the eastern Bering Sea (Unalaska
Island and Golovnin Bay) during 1929-46 are listed in Table 111.6.13. Herring
statistics from the fisheries of Japan and the U.S.S.R. in the eastern Bering
Sea are shown in Table 111.6.14. In addition, catches of herring by Japanese
and Soviet trawl fisheries east of 180° during fishing years 1967-68 to
1974-75 and by the Japanese, gillnet fishery off the Bering Sea coast of
Alaska during 1968-75, with respective CPUE's, are shown in Figures 111.6.27
and 111.6.28.

Table 111.6.13 .--United States herring catches in the eastern
Bering Sea, 1929-1946, in metric tons (from Rumyantsev and
Darda 1970).

Year	Unalaska Island	Golovnin Bay	Total
1 9 2 9	1,141.9	170.7	1,312.6
"1930	1,738.2	3 9 7 . 0	2,153.2
1931	957.9	88.9	1,046.8
1932	2,276.9	135.5	2,412.4
1933	1,438.2	33*4	1,471.6
1934	1,390.9	2.4	1,393.3 "
1935	2,188.0	14.1	2,202.1
1936	1,251.1	*	1,251.1
1 9 3 7	525.4	5.0	530.4
1938	465.5	9.0	474.5
1939-44	*	*	*
1945	68e0	*	68.0
1946	*	*	*

* Unknown

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Table 111.6.14.--Catches of Pacific herring (metric tons) by Japanese and Soviet fisheries in the eastern Bering Sea, 1961-77.

Year	Japanese Fisheries			Soviet Fisheries	Total Eastern Bering Sea
	Area		Total		
	180°-170°W	East of 170°W			
1961				9,800	9,800
1962	311	2	313	24,450	24,763
1963	133	11	144	'47,060	47,204
1964	853		853	38,950	'39,803
1965	771	–	771	10,000	10,771
1966	3,386		3,386	5,000	8,386
1967	2,502	209	2,711		2,711
1968	16,697	1,005	17,702	22,255	39,957
1969	30,057	4,783	34,840	94,401	129,241
1970	26,599	1,721	28,320	117,202	145,522
1971	15,569	4,661[a/]	20,230[a/]	23,000	43,230
1972	5,736	602	6,338	54,000	60,338
1973	29	1,922[b/]	1,951[b/]	34,361	36,312
1974	312	5,130	5,442	19,800	25,242
1975	1,003	804	1,807	18,504	20,311
1976	3,095	2,575	5,670	7,226	12,896
1977	c/	c/	c/	13,144	13,144

a/ Includes 8 metric tons from the Aleutian Islands.
b/ Includes 41 metric tons from the Aleutian Islands.
c/ Data not available.

Data sources: Japanese catches 1962-1973 from International North North Pacific Fisheries Commission, Statistical Yearbooks 1962, 1964-74; 1974-77 from data furnished by the Fisheries Agency of Japan to the Int. North Pac. Fish. Comm. Soviet catches 1961-64 from Rumyantsev and Darda (1970), 1965-67 from Pruter (1976), 1968-77 from data furnished by the U.S.S.R. in files of the Northwest and Alaska Fisheries Center, Seattle, Wash.

CONSERVATION AND MANAGEMENT REGULATIONS

Herring fishing in the early years of the industry in Alaska was not regulated until the enactment by Congress of the White law in 1924. Under that law, the U. S. Department of Commerce defined open seasons in various areas and limitations upon the types of gear (Rounsefell 1931, Rounsefell and Dahlgren 1932). Because of fluctuating catches, catch quotas were imposed by the U. S. Fish and Wildlife Service in 1940 to regulate the fishing intensity in the southeastern Alaska, Prince William Sound, and Kodiak districts, depending upon the condition of the stocks (International North Pacific Fisheries Commission 1961c). The quotas were discontinued in the Prince William Sound and Kodiak districts in 1953 but were continued and established annually in southeastern Alaska. Regulation by the U. S..Fish and Wildlife Service was by closure of areas to fishing and by the establishment of quotas, all determined by three measures: catch per boat ton day (indicating abundance), abundance of herring as determined by aerial surveys of spawning beaches during March and April, and age composition (Kolloen and Smith 1953, Administration of Alaska Commercial Fisheries 1956 4/).

After Alaska obtained statehood, the U. S. Fish and Wildlife Service relinquished control of inshore herring fisheries on January 1, 1960. The State of Alaska continued to regulate the fisheries by closure of areas and by annual catch quotas in southeastern Alaska. In the early 1970's, annual quotas were re-established in the Kodiak, Cook Inlet, and Prince William Sound areas, in addition to those in southeastern Alaska. The quotas are based on harvesting 10-20% of each major stock using data on total biomass available and age and growth analysis (Blankenbeckler 1976). Alaska also regulates net types, net sizes, and mesh sizes.

Any regulation of herring fisheries by foreign nations in international waters has been self-imposed or by agreements between governments. Under terms of the International Convention for the High Seas Fisheries of the North Pacific, entered into force in 1953, Japan agreed to abstain from fishing for herring in the northeast Pacific Ocean. As mentioned previously, the protected stocks of herring were removed in 1959 from abstention. In the mid-1970's, quotas were established by bilateral agreements by Japan and the U.S.S.R. with United States for Japanese and Soviet catches in the eastern Bering Sea. Japan was restricted to specific quotas each year from 1973 to 1975-76, and the U.S.S.R. "was limited beginning with 1975-76 (Pruter 1976, International North Pacific Fisheries Commission 1977). Foreign herring fisheries in the eastern Bering Sea and the Gulf of Alaska have been restricted since March 1977 when the United States adopted its 200-mile Fishery Conservation Zone. In 1977, Japan was allocated a quota of 5,800 mt in the Bering Sea/Aleutian region and the U.S.S.R. was allocated 13,600 mt.

4/ Administration of Alaska Fisheries. 1956. Progress report and recommendations for 1957. U. S. Fish Wildl. Serv., Admin. of Alaska Commer. Fish., Juneau, Alaska. 34 p.

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SUGGESTIONS FOR FUTURE RESEARCH

In spite of nearly 100 years of commercial herring fishing in Alaska and
a long history of research and management by several agencies, knowledge
of many aspects of the herring stocks and biology is incomplete or lacking.
Catches have fluctuated with changes in availability of fish and with demand
determined by markets for herring and herring products. Management of stocks
is complicated by the entry of foreign nations into the fisheries and by
changing markets. In addition, increasing world population needs for animal
protein will stimulate harvesting the Alaska herring stocks which are not
now being used to the maximum.

To manage the herring fisheries in the future, research is needed to measure
annual recruitment by increased sampling of the commercial catch, including
catches of foreign nations in Alaska waters. Other studies should sample
juvenile fish offshore and tag fish to determine migration patterns and
the contribution of offshore stocks to inshore fisheries. Biochemical genetic
techniques should be used to identify specific races or stocks. Research
should examine the effects of harvesting roe as compared to the effects
of capturing mature fish, and the total effect of both fisheries, on the
overall abundance and recruitment. Behavioral and physiological studies
would aid management's understanding of herring schooling and their reactions
to fishing gear and to stimuli. The effects of various physical, chemical,
and biological environmental factors on survival and recruitment also should
be studied.

THE SMELTS (Family Osmeridae)

Although members of the smelt family have been an important part of the
diet of North American natives since prehistoric times, our knowledge .
of this group of fish is quite limited. The main reason for this lack
of knowledge is that there has been little commercial fishing of most
of the smelt species. The surf or silver smelt (Hypomesus pretiosus) and
the eulachon (Thaleichthys pacificus) support moderate sized fisheries
in British Columbia and Washington (Hart and McHugh 1944 , Scott and Cross-
man 1973, Browning' 1974), but the smelts are generally considered one
of the presently underexploited resources. Because research has been pri-
marily focused on commercially important species, the smelts have received
relatively little attention. Controversies over the smelt systematic
and common misidentification of the various species have confused the
information that has been accumulated. Most studies that have been con-
ducted have concentrated on the inshore spawning habits of this family
with the result that the marine life history and distribution has been
almost completely ignored.

IDENTIFICATION .

Scott and Grossman (1973) described the members of the smelt family as
being small, generally silvery fishes with elongate, laterally compressed
bodies. Other family features include a relatively large mouth, an adipose
fin, cycloid scales, and a lateral line. "

Being fairly similar in appearance, individual species are frequently
confused. Pond smelt are often classified as the closely related surf
smelt (McAllister 1963), longfin smelts are commonly grouped with the
more common eulachon, and the common names for one species are sometimes
used in conjunction with the scientific name of another species. A case
in point is in the report by Warner (1976), "Probably locally more important
than herring are the hooligan (capelin, Mallotus villosus), which spawn
in large numbers along the north Peninsula." While capelin is a commonly
used name for Mallotus villosus, hooligan generally refers to the eulachon,
Thaleichthys pacificus. Similarly, in the Gulf of Alaska both capelin
and eulachon are sometimes called candlefish. The name smelt may refer
to the whole family or just to the rainbow smelt, Osmerus mordax, (Scott
and Grossman 1973). Because of the confused systematics of the genus Osmerus,
rainbow smelt (Osmerus mordax) and boreal smelt (Osmerus eperlanus) might
be thought to be separate species (refer to pelagic species code list,
Appendix A) while in fact they are synonomous.

DISTRIBUTION

Figure III.7.1 gives the general distribution of the smelt family. Distri-
bution of individual species is given in the separate species summaries
following, and in the charts in the section on the historical data records.
Unfortunately, distribution and estimates of abundance are based on limited
information. Data compiled by the commercial fisheries and research institutes
frequently tabulate the smelt catch data by family only, group the smelt

catches with herring, or combine it with a variety of species in the category "other roundfish." One must also keep in mind that in most cases the smelts are not being actively fished and, if anything, their capture is avoided by the use of gear which will allow them to slip through, or by not fishing areas in which they are present in large concentrations.
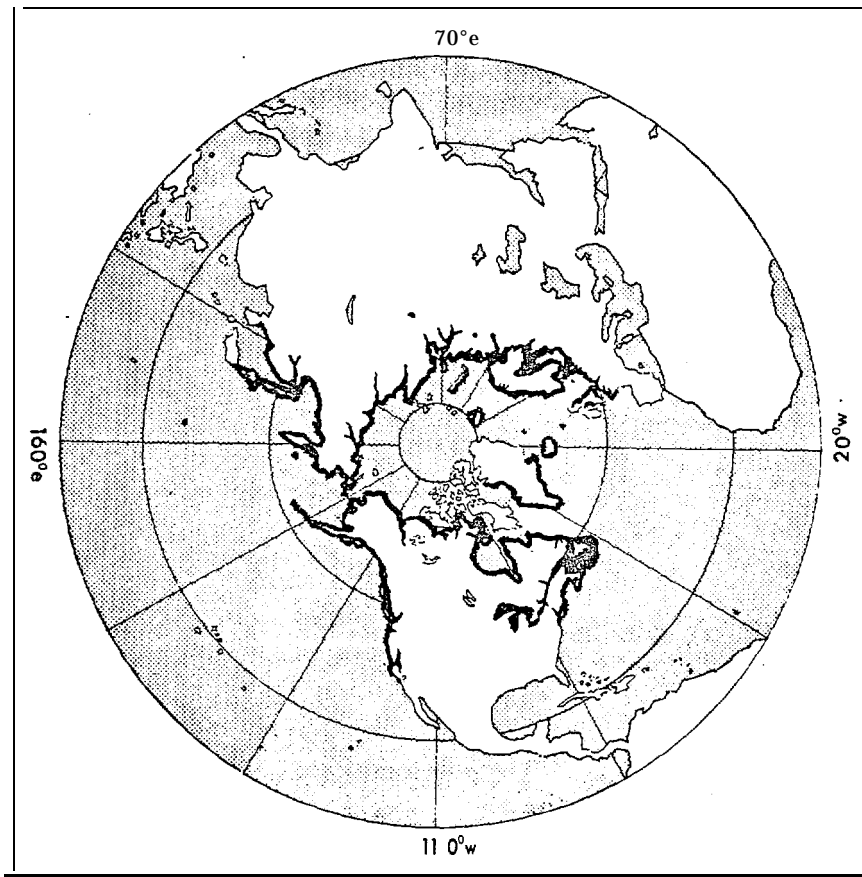
Figure 111.7.1.--World distribution of the smelts (from Scott and Crossman 1973).

POTENTIAL CONTRIBUTION. TO DOMESTIC AND INTERNATIONAL ECONOMY

Most of the smelt species have been shown to be very important in the
food chain as forage for a large variety of fish, birds, and marine mammals.
Some species have been, and still are, prominent features in the culture
and sustenance of native Americans. In addition, sport fishing for certain
smelts has become increasingly popular recently. While Alaska has not
had much of a commercial smelt fishery in the past, there may be new interest
in establishing one. The Alaska Department of Fish and Game reported (unpub-
lished catch data) that in 1974 two landings of smelt weighing a total
of 37,480 pounds were made at Blying Sound on the Kenai Peninsula. It
is not unreasonable to suppose that in time a commercial smelt fishery
may be established in Alaskan waters. At present, eulachon and surf smelt
support small fisheries elsewhere on the Pacific coast, and both capelin
and rainbow smelt are being fished in the Atlantic.

SUGGESTIONS FOR FUTURE RESEARCH

Since there is very little known about the size of Alaskan smelt stocks
and their marine life history, exploratory surveys using acoustic gear
backed up with net sampling would be very beneficial in obtaining estimates
of sustainable catch. Knowledge of the time and location of smelt concen-
trations and any seasonal change in condition of the flesh would also
be important. Various types of gear should be tested for efficiency in
catching these small fish. The creation of a market is ultimately very
important in the development of a fishery because it must be economically
feasible to catch smelts. However, as exploitation of presently fished
species reaches its upper limits, presumably the underutiLized resources
will receive more attention and a higher price on the world market.

More specific information from literature about six species of smelts
follows. These species are the pond smelt (Hypomesus olidus), the surf
smelt (Hypomesus pretiosus) , the capelin (Mallotus villosus), the rainbow
smelt (Osmerus mordax), the longfin smelt (Spirinchus thaleichthys), and
the eulachon (Thaleichthys pacificus).

POND SMELT (Hypomesus olidus)
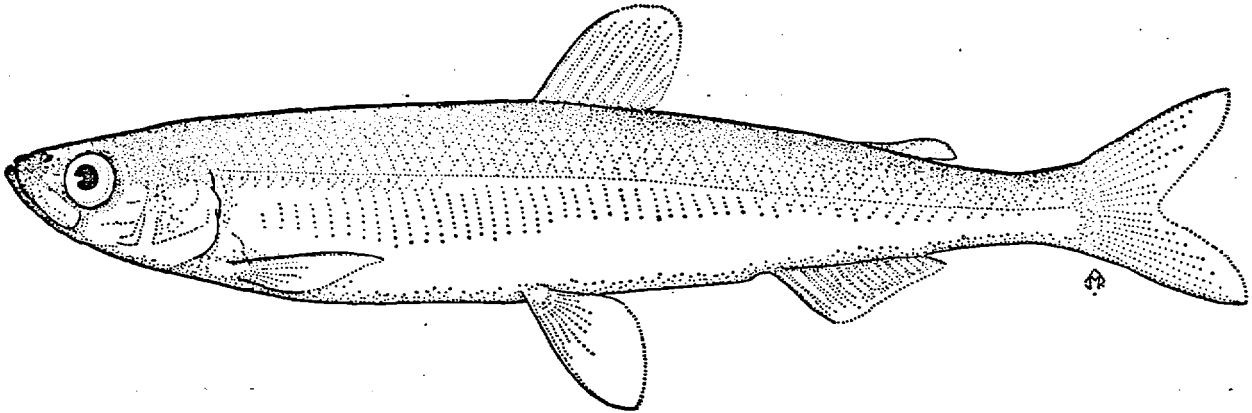
Figure III.8.1--The pond smelt, Hypomesus olidus (from Scott and Grossman
1973).

IDENTIFICATION

The pond smelt has been frequently confused with both of the other
species of Hypomesus: H. pretiosus, the surf smelt, and H. transpacificus
(McAllister 1963, Andriyashev 1954), so the literature must be used
with care. The surf smelt is primarily a marine species, while 'he
pond smelt lives much of its life in fresh water, venturing occasionally
into bays or estuaries (Rass, Kaganovskii, and Klumov 1955). As with
surf smelt, a long list of scientific names have been applied to it
(adapted from Berg" 1948, Andriyashev 1954, McAllister 1963):

> Salmo inghaghitsch Walbaum 1792
> Salmo (Osmerus) spirinchus Pallas 1811
> Salmo (Osmerus) olidus Pallas 1811
> Hypomesus olidus Günther 1866
> Osmerus (Spirinchus) thaleichthys Jordan and Evermann
> Mesopus olidus Scofield 1899
> Hypomesus japonicus Hubbs
> Hypomesus olidus bergi Taranets 1935
> Hypomesus olidus drjagini Taranets 1935
> Hypomesus olidus olidus Taranets 1937
> Hypomesus sakhalinus Hamanda 1957

In the Soviet Union, both pond smelt and surf smelt are known by the name malorotaya koryushka (Berg 1948, McAllister 1963). Another Russian name for pond smelt is ogurechnik, meaning "cucumber" because of its similar odor (Nikol'skii 1954), and in Japan it is called ishikari-wakasagi (McAllister 1963).

Some investigators have divided HYpomesus olidus into a number of sub-species such as olidus, bergi, and drjagini (Walters 1955), but McAllister (1963) feels that there is too much variability within the populations to warrant separate designations.

Pond smelt have fewer vertebrae and are somewhat smaller than surf smelt, reaching a maximum length of only 185 mm (Andriyashev 1954, Rass et al. 1955). In addition, it is recognized by the punctate borders on the dorsal scales; the fine speckling on the snout, operculum, and unpaired fins; and the silvery band along the incomplete lateral line (Berg 1948, Rass et al. 1955, McAllister 1963). Descriptions of the general body color vary from silvery gray to light brown to olive green (Rass et al. 1955, McAllister 1963, Scott and Grossman 1973). During the spawning period, males have tubercles on the head, fin rays and body scales, while the female has few or none (McAllister 1963).

DISTRIBUTION

The pond smelt is found in fresh and brackish water along the coasts of Asia and North America (Berg 1948) (see map, Fig. 111.8.2). In Asia its known range is from the basin of the Kara Sea in the west, along the north and east coasts of the U.S.S.R. to Korea and northern Japan in the south (Walters 1955). It is thus found in the coastal waters of the Bering Sea, the Sea of Okhotsk, and the Sea of Japan (Andriyashev 1954). In North America it occurs from California north to the Kobuk River in Alaska and east to the MacKenzie watershed (Scott and Crossman 1973).

Although some authors have indicated that on the North American continent it is totally a freshwater species (Scott and Grossman 1973), Marsh and Cobb (1908) noted that during the nonspawning season (October to June), pond smelt were found at Port Heiden on the Alaska Peninsula and in the coastal waters of southeast Alaska. In addition, data in the Section IV, Historical Data Record of Non-salmonid Pelagic Fishes, show that they occur in Bristol Bay.
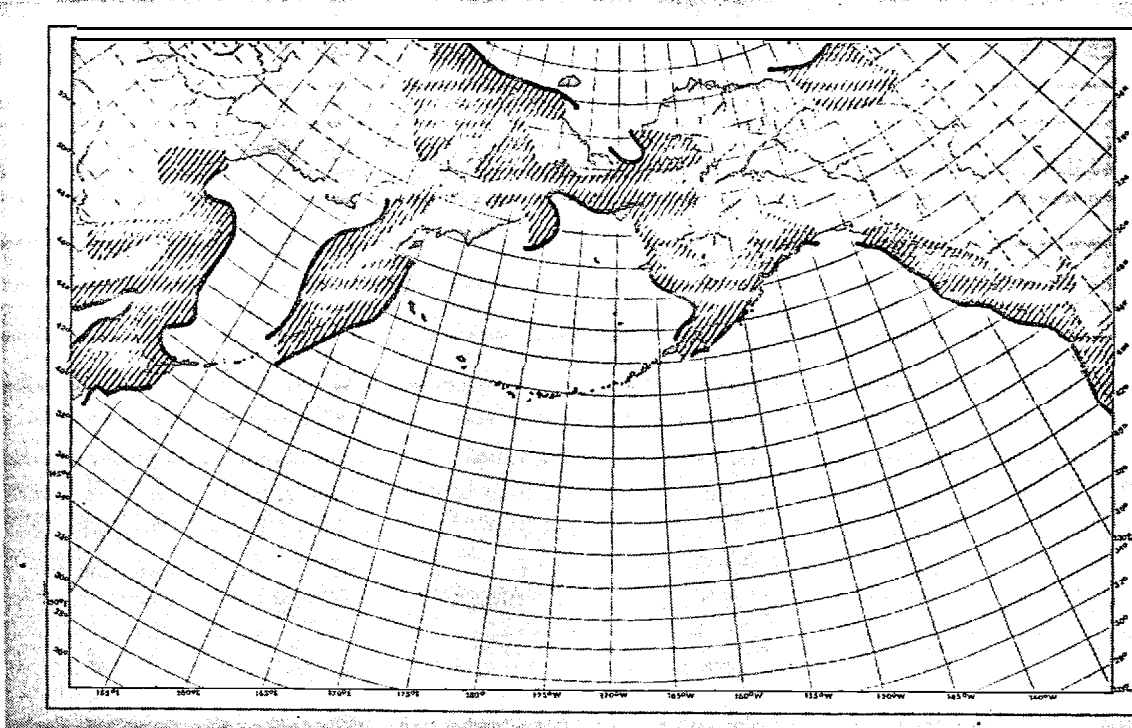
Figure III.8.2--Distribution of pond smelt (mapped from information in Marsh and Cobb 1908, Berg 1948, Wilimovsky 1954, McAllister 1963, Scott and Crossman 1973). (Open borders indicate uncertain distribution).

LIFE HISTORY

Reproduction

Because this species is a freshwater spawner, its reproductive biology will not be discussed in detail in this report. There are two **forms** of pond smelt: a semi-diadromous form which matures at the age of two to three years, and a **lake** form which reaches maturity in one to two . years **(Rass** et al. 1955). Migratory **smelt** spawning in the rivers of Peter the Great Bay (U.S.S.R.) produce 6,000 to 10,500 eggs per female while the nonmigratory fish in Lake **Bolon (Amur** River) have a lower

fecundity of 1,200 to 3,800 eggs (Berg et al. 1949). The spawning runs
near Peter the Great Bay are from April to mid-May (Berg et al.), and
at St. Michael, Alaska, the run begins as soon as the ice on the rivers
is lifted enough to allow them to pass under (Turner 1886). According
to Musienko (1970), pond smelt spawn near banks in areas of swift currents
and stony bottoms. Scott and Crossman (1973) mentioned that pond smelt
spawn over a bottom covered with organic debris. The eggs are demersal,
adhesive, and about 1 mm in diameter (Berg et al. 1949).

Nutrition and Growth

Growth

Pond smelt eggs hatch within 11 or 12 days when incubated at temperatures
of 11 to 15° C (Nikol'skii 1954). The larvae at hatching (see Fig. 111.8.3)
are approximately 4.6 mm in length (Berg et al. 1949). In ten to eleven
days after hatching when the yolk sac has been resorbed, the larvae
migrate to sea (Rass et al. 1955). Growth rate is dependent on geographic
location, water temperature, nutrition, and various other factors.
Smelt in Black Lake, Alaska, reach 60 mm in length by the end of the
first year and 80 mm by the end of the second year (McPhail and Lindsey
1970, as cited by Scott and Crossman 1973). The largest specimen which
McAllister (1963) examined was 102 mm in length, but Berg et al. (1949)
reported that the average and maximum lengths of adult pond smelts
in the Gulf of Anadyr are 126 and 185 mm respectively.
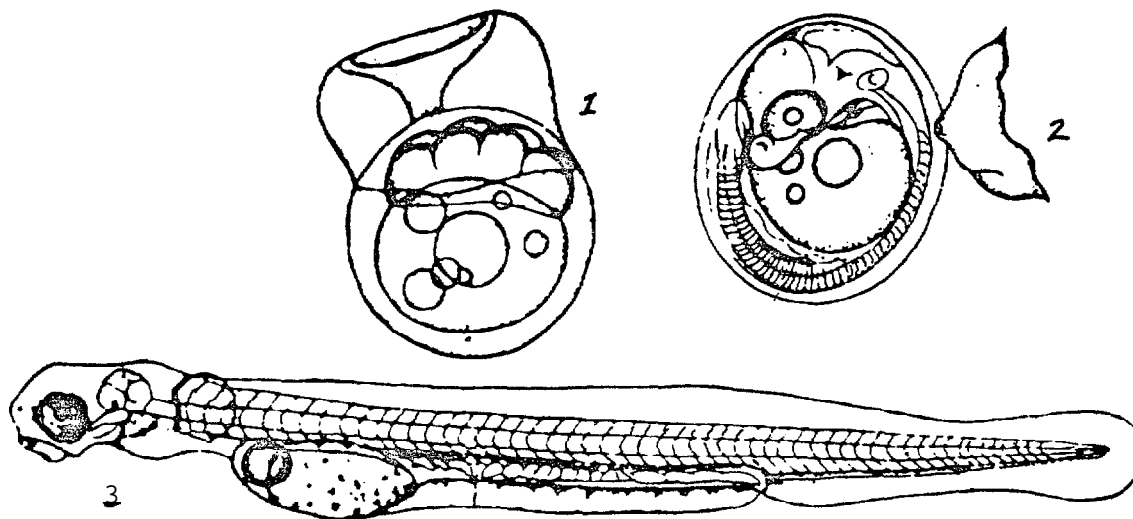
Figure 111.8.3 .--The development of the pond smelt, Hypomesus olidus: 1- the
egg in the eight-blastomere stage; the membrane is just
coming off, 2- the beginning of heart pulsation; 3- the larva
emerged from the membrane (adapted from Soin 1947 by Nikol'skii
1954).

Food and feeding

Berg et al. (1949) observed that the nonmigratory pond smelt feed on insect larvae and small crustaceans such as Bosmina, Neomysis, and Limnocalanus. While the marine food of the migratory smelt was not mentioned, it probably has a similar diet, feeding on organisms such as copepods and amphipods.

Predators and Competitors

According to Marsh and Cobb (1908), pond smelt are frequently found in the stomachs of king salmon. It is assumed that they have other enemies such as marine mammals, and birds, in addition to predatory fish.

Possible competition may exist between pond smelt and juvenile sockeye salmon since they are both pelagic feeders (Scott and Grossman 1973).

Behavior

Although nonmigratory pond smelt are common in northern lakes and streams, migratory forms also exist which move downstream to the freshened portions of the sea but return to the streams and ponds during the spawning season (Berg et al. 1949).

According to Berg et al., schools of pond smelt frequently mix with schools of surf smelt and the two smelt species have been observed swimming up river together.

POPULATION DYNAMICS

Rass et al. (1955) reported that abundance of pond smelt in the northwest Pacific Ocean increases from south to north. It is most numerous in the Sea of Okhotsk while it is fairly rare in the Arctic Ocean. Very little is known concerning the abundance of North American pond smelt, but it was once considered very common near St. Michael, Alaska (Turner 1886).

FISHING

In the past, pond smelt were considered an important part of the diet of natives in western Alaska (Marsh and Cobb 1908). Fish were caught during the annual spawning runs with long sticks or with dip nets, then the smelt were sun dried on strings of twisted grass (Turner 1886). Although no commercial fishery presently exists, pond smelt are still captured for local consumption both in North America and in Asia, especially in Japan and Korea (Scott and Grossman 1973).

SURF SMELT (Hypomesus pretiosus)
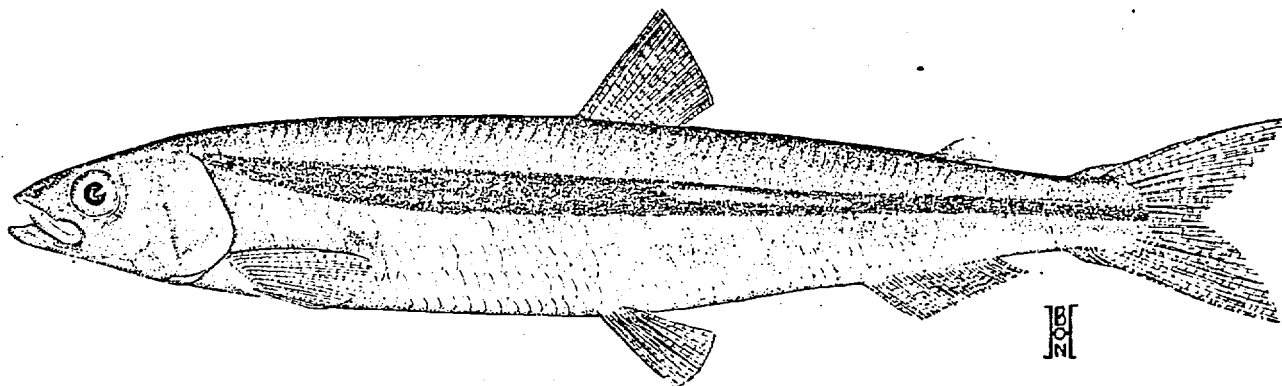
Figure III.9.1.—The surf smelt, Hypomesus pretiosus (from Hart 1973).

IDENTIFICATION

Three species of ypomesus are generally recognized at present, two of which have two subspecies each. Hypomesus pretiosus pretiosus is the surf smelt which inhabits the North American coastline, and the closely related H. pretiosus japonicus frequents the Asian side of the Pacific Ocean (McAllister 1963). Although the two are similar, both in habits and appearance, they can be readily distinguished and their stocks do not intermingle (Hart 1973). The pond smelt, Hypomesus olidus, on the other hand, is sympatric with the American surf smelt and, because it is frequently confused with H. pretiosus, the literature must be used with care (McAllister 1963). In addition, a variety of scientific names have been used in referring to the surf smelt, thus adding to the confusion (according to Berg 1948):

    Argentina pretiosa Girard 1884
    Osmerus oligodon Kner 1865
    _ japonicus Brevoort   1 8 5 6
    Mesopus olidus Shmidt 1904
    Spirinchus verecundus Jordan and Metz, 1913-1914
    Hypomesus verecundus Hubbs
    Hypomesus japonicus Hubbs
    Hypomesus olidus Berg 1932
    Hypomesus pretiosus Schultz and DeLacy 1935

In some regions, the common name silver smelt is used, and in the Soviet Union the fish is called Kaliforniiskaya malorotaya koryushka (or California smallmouth smelt) (Berg 1948).

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The surf smelt can be distinguished from other smelts by the small mouth,
a silvery band along the side, the incomplete lateral line canal, the small
sickle-shaped adipose fin, and the location of the dorsal fin origin in
front of the pelvic fin insertion (Hart and McHugh 1944, Hart 1973). Breeding
males can be readily differentiated from females by their size, coloration,
and presence of small tubercles on the sides, head, and fins (Schaefer 1936).
Males are generally several millimeters shorter and slimmer than females
and have slightly longer pectoral fins (Schaefer 1936, Yap-Chiongco 1941).
Females are larger, and during spawning they have a deeper and thicker body
due to the large quantities of eggs they are carrying (Yap-Chiongco 1941).
The dorsal surface of the male is a dull brownish-green, shading into a
golden color ventrally while the back of the female is a bright shiny green
and the belly is silvery-white (Thompson et al. 1936, Schaefer 1936).

DISTRIBUTION

The surf smelt has been found along the Pacific coast of North America from
Long Beach Harbor in southern California to Prince William Sound in Alaska
(McAllister 1963, Hart 1973) (see map, Figure 111.9.2). In addition, a few
specimens have been found in Sitkalidak Strait near Kodiak, and in Chignik
Lagoon on the south side of the Alaska Peninsula (lat 56o 20' N, long 158°
30' W) (Phinney and Dahlberg 1968). The Asian subspecies, H. pretiosus japonicus,
ranges between Tartary Strait (near Sakhalin) to the coast of northeast
Korea (Berg 1948).

Although the surf smelt is primarily a marine species, it sometimes enters
brackish water to spawn and has even been found as far as 10 miles up the
Sandy River in Oregon (McAllister 1963). Stomach-content analysis of young
smelt indicates that they sometimes swim up rivers to feed, and may alter-
nate between a marine and a freshwater environment during their early life
history (Yap-Chiongco 1941).

LIFE HISTORY

Reproduction

Age and Size at Sexual Maturity, Sex Ratios

Schaefer (1936) indicated that some surf smelt in Puget Sound spawn at the
end of the first year, but that these are nearly all males. Females of the
same age and larger size do not spawn until later, usually the second year
(Loosanoff 1937, Yap-Chiongco 1941).

Like capelin, the surf smelt does not form scales until the latter part
of the first year and, as a result, the first ring is not formed until the
second winter (Loosanoff 1937). Among the spawning population studied by
Loosanoff, approximately 98% of the surf smelt had just one winter ring
and the remaining 2% had two rings and were thus probably three years old.
Yap-Chiongco (1941) later investigated Puget Sound smelt and observed quite
different percentages. He found that 42.7% were one-year fish; 54.4% were
two years old, and 2.9% were three years of age. The observed discrepancy
in age composition of the spawners may have been caused by the difference
in the time of year at which the samples were taken, for greater percentages
of younger fish have been found toward the end of the spawning period (Yap-
Chiongco 1941).

Schaefer (1936) reported that larger individuals of the same age group reach
maturity sooner than the smaller ones. Early in the spawning season only
large males accompany the females on the spawning beaches, but as the season
progresses the average" size of the spawning males decreases (Yap-Chiongco
1941). In some areas the length frequencies of a spawning population indicate
that there is only one major length-group and hence one age-group, while
in other areas the length distributions (Fig. 111.9.3) suggest-two or more
such groups. Yap-Chiongco found a mature male as small as 81 mm, but that
fish may have been exceptionally precocious because others of the same length
were found to be immature. The smallest mature fish captured by Schaefer
(1936) was a male 90 mm in length. Females mature at a larger size than
males as was previously shown in Figure 111.9.3.

The disproportionate number of males on the spawning grounds led Swan (1881a)
to suggest that the males and females spawn at different times--the females
first leaving their eggs and the males later swimming in and fertilizing
them with clouds of milt. Later investigations, however, have shown that
no such segregation of sexes occurs at the actual time of spawning. As the
schools arrive on the spawning grounds they may be unisexual in character,
but mixing occurs soon after (Loosanoff 1937). Throughout the breeding season
males outnumber females, the males sometimes constituting 82 to 95% of the
spawning population.
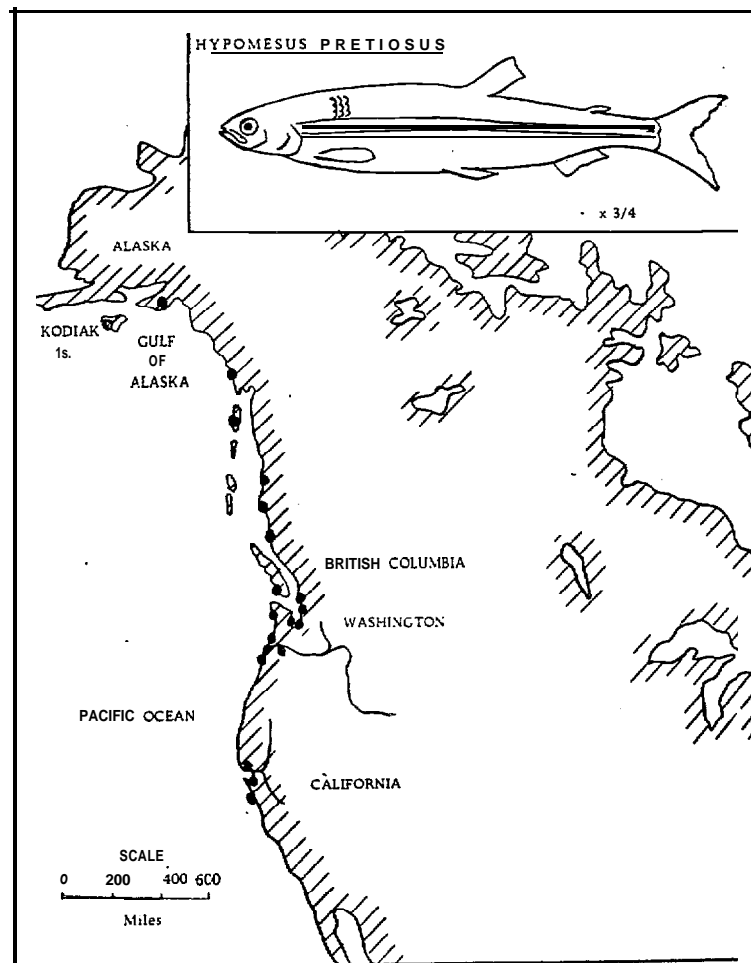
Figure 111.9.2 .--Pacific coast of North America showing the general
    distribution (solid circles) of surf smelts, Hypomesus pretiosus.
    Inset shows lateral view of an adult smelt (from Leong 1967 which
    was modified from McAllister 1963).

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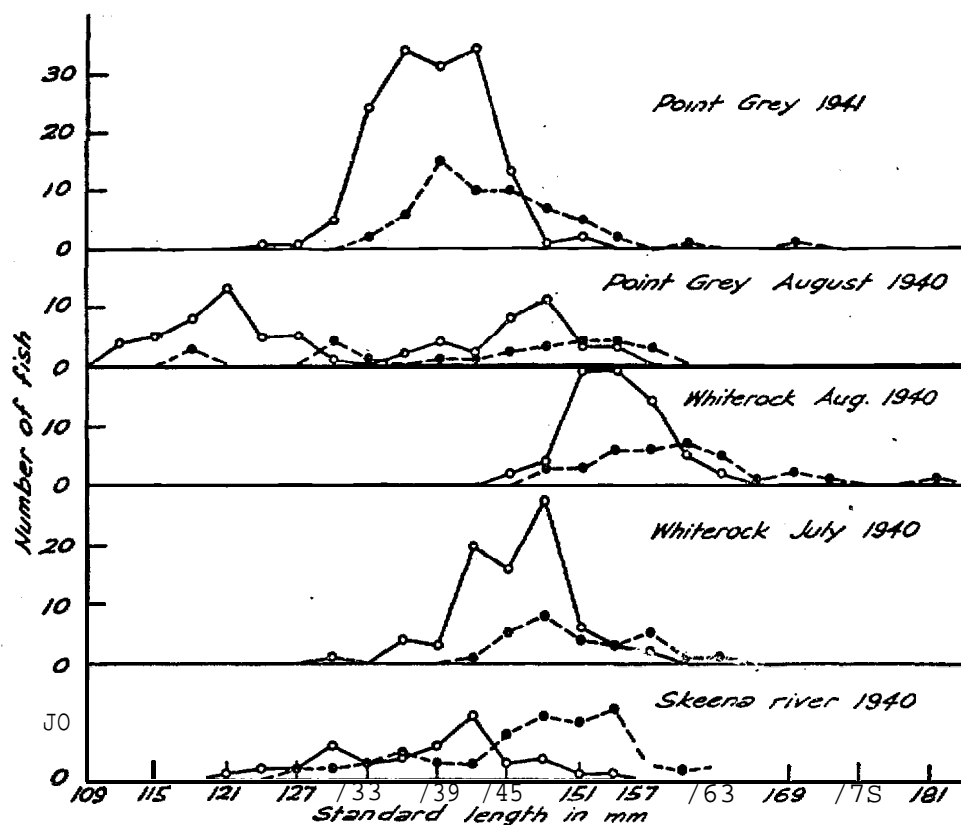
Figure 111.9.3.--Length distribution of surf smelt in samples from various localities in British Columbia. Males, solid line; females, broken line (from Hart and McHugh 1944).

Fecundity

Leong (1967) summarizes the data on surf smelt fecundity in Table 111.9.1. In general, the larger the size of the female, the greater the number of eggs it produces, the total weight of which average 22% of the body weight (Yap-Chiongco 1941, Branson 1972). There are indications that a female may spawn several batches of eggs during a given season, and each batch of 1,320 to 29,950 eggs may take several days to be laid (Hart and McHugh 1944, Hart 1973).

Table 111.9.1.--Estimates of surf smelt fecundity by various investigators (from Leong 1967).

Authority	Year of collection	Sample size	Fish length (cm.)		Fecundity		Locality
			Mean	Range	Mean	Range	
Loosanoff (1936)	1930	3	15.6	ʺ13. s-18.0 .	28492.	17700-39250	Utsaladdy
Thompson et. al. (1936)	1932	5	16.0	15.0 -16.9	8371	4020-13714	Vicinity of Cedar Creek
Schaefer (1936)	1935	61	13.7	10. S-17.8	14031	2S00-29300	Utsaladdy; Pesm Cove
Yap-Chiongco {1S41)	1939	5	14.2	12.0 -1S.9	14579	657S-22169	Maple Grove, Camano Is.

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Mating and Fertilization

Spawning Area

Surf smelt seem to be very selective of their spawning grounds, for only certain areas of particular beaches are used by smelt year after year (Frey 1971). A number of factors may be involved: the particle size of the substrate, the slope of the beach, the exposure of the beach, and the proximity of streams (Loosanoff 1937, Yap-Chiongco 1941, Frey 1971). Sumner spawning grounds may be either on sheltered beaches in bays or on shores exposed to the full force of the surf, but they generally are shaded to some degree from the sun (Schaefer 1936, Hart and McHugh 1944). Hart and McHugh found that in winter protection from the sun is not as important as shelter from heavy winter surf, so different beaches may be used according to the season. Surf smelt seem to select substrates with fine gravel and sand mixed with pebbles or broken shells (Thompson et al. 1936, Schaefer 1936, Leong 1967). Hart and McHugh (1944) noted a preference for areas having some fresh water seeping through the gravei substrate. Normally Hypomesus pretiosus spawns in the surf at the edge of a beach where the water is only a few inches deep (Schaefer 1936), but river spawming may also take place because this smelt has been seen entering the mouth of the Sedanka River in the U.S.S.R. along with the freshwater-spawning pond smelt (Berg 1948).

Time of Spawning

In Puget Sound , where most surf smelt studies have taken place, it was discovered that there are at least three different races of surf smelt, each with a different but overlapping spawning season. One race spawns from mid-May to mid-October, another group spawns from mid-August to the first of December, and a third race spawns from mid-August to the first of March in the following year (Yap-Chiongco 1941). Thus, Hypomesus pretiosus can be found spawning somewhere in Puget Sound every month of the year (except possibly April) even though at any one beach spawning may occur during only two to four" months of the year (Schaefer 1936).

Spawning Conditions

Within the spawning season for a particular population of surf smelt there is some variation in intensity of the runs. According to Loosanoff (1937), there is more activity during a series of increasingly high tides than during progressively lower tides. He said.the tides must also reach 8 to 12 feet above the mean low water mark. As a further modification, while some spawning takes place during every tide of a favorable series, larger runs occur on calm days than when the seas are high (Hart and McHugh 1944). Spawning activity also is usually greater during afternoon or early evening tides than during the tides which occur in the morning or after dark (Yap-Chiongco 1941) .   . ‾

Schaefer (1936) described the mating behavior of the surf smelt. Approximately one to one and one half hours before the high tide, groups of smelt approach the shore and swim rapidly back and forth parallel to the beach and a few feet offshore. One to four males accompany a single female, pressing close together in a formation with the vents aligned. As they swim together near the bottom they emit eggs and sperm which are quickly covered with the fine sand that shifts with the motion of the surf. Following the spawning act, which lasts less than a minute the formation splits up and the members return to slightly deeper water. The same female may spawn several times in close succession, depositing only a few eggs each time. This activity continues until an hour or more after the tide has begun to ebb.

Frequency

After observing three size groups of surf smelt ovarian eggs, Schaefer (1936) surmised that the female spawns several times during a season. He felt that successive batches of immature eggs mature and are spawned and the unripe eggs remaining at the end of the season are resorbed. Some investigators question Schaefer's interpretation of the ovarian size groups (Loosanoff 1937, Hart and McHugh 1944) and, as it is difficult to document successive spawnings of a particular fish, the issue is still undecided. It is recognized, however, that since the female lives up to three years, it may spawn in the second and third year of life while some males may spawn in both the first and second years (Yap-Chiongco 1941, Loosanoff 1937).

Egg s

The fertilized eggs of surf smelt have a diameter of approximately 1.02 mm, a small perivitelline space, a yolk with many oil droplets, and a yellowish transparency (Schaefer 1936, Loosanoff 1937). The outer membranes are very adhesive , and like those of other smelt eggs they break and invert to form attachment stalks by which the eggs are anchored to the larger particles in the substrate (Loosanoff 1937, Thompson et al. 1936).

Loosanoff (1937) studied the viability of eggs found at various tide levels and depths under the sand. He found the majority of surf smelt eggs between the 8 and 11.5 foot upper tide levels and at depths in the sand from 0.5 to 1.5 inches. All of the eggs were fertile and could withstand long periods of dessication but the depth in the substrate seemed to be an important factor. Mortality for eggs buried up to 2.5 inches was only 3 to 5%, but those at a 3.5 inch depth had a mortality of 65%, and those buried deeper than 4 inches failed to develop at all. Poor water circulation at deeper substrate levels results in oxygen depletion and a buildup of wastes which may be responsible for the increased mortality.

The development of the embryo is described in some detail by both Loosanoff (1937) and Yap-Chiongco (1941) and will not be repeated here. Normally on the tenth or eleventh day, the eggs become detached, the action of the surf releases the eggs from the sand, and hatching soon follows (Loosanoff 1937). According to Loosanoff, however, hatching may be somewhat delayed by a series of low tides and does not occur until the tides are high enough to reach the eggs. Colder water temperatures during the development of fall and winter spawned eggs also postpones hatching (Hart 1973).

Growth

Newly hatched surf smelt larvae are **nearly** transparent except **for** an orange
eye, they have **a** fin which extends most of the way around the body, and
they are about 3 mm in length (Schaefer 1936, Yap-Chiongco 1941). Upon **emer-
ging** from the egg they are very active, and since **the** yolk sac is quite
small they are able to swim quite rapidly in a normal horizontal **position**
(Loosanoff 1937, Yap-Chiongco 1941). Being positively **phototrophic,** they
are attracted to the surface water of the spawning grounds where they have
been collected in plankton nets (Schaefer 1936, Yap-Chiongco 1941). **Post-
larvae** become negatively **phototrophic,** they begin to form scales when they
are 5.5 to 6.8 cm long, and by the time they are 7 cm in **length** they have
all of the features of the adult except maturity (Yap-Chiongco 1941). **Loosa-
noff (1937)** reported that young smelt in this stage of growth are found
in the lower **parts of some** Puget Sound rivers by late fall or early winter.
Their growth rate is quite dependent on water temperature; as a result,
very few winter-spawned smelt become **mature** by the end of the first year
(Schaefer 1936). As previously mentioned, females are generally larger than
males of the same age and, since they also tend to live longer, the **larger**
fish are predominately females (Schaefer 1936, Yap-Chiongco 1941). In the
south **part** of their range surf smelt attain the greatest lengths, reaching
a maximum of 30.5 cm (12 inches) in California and only 22.2 cm (8.75 inches)
in British Columbia (Hart 1973). According to Hart and McHugh (1944), more -
over, the average size of surf smelt caught by the commercial fishery in
British Columbia is about 13.54 cm (5.33 inches).

Food and Feeding

The surf smelt has a varied diet. They have been found to consume **phyto-**
plankton and copepods (Loosanoff 1937); amphipods, euphausiids, shrimp larvae
and marine worms (Hart and McHugh 1944); insects, Oikopleura, combjellies,
and larvae of crabs, **eulachon,** walleye **pollock,** and **prickleback** (Hart 1973).
Young fingerlings caught near the mouth of rivers had Diptera larvae and
mayfly nymphs in their stomach contents, indicating that they may at least
occasionally swim up the rivers to feed (Yap-Chiongco 1941). Surf smelt
generally do not feed during the spawning season, possibly because the huge
volume of sexual products compresses the digestive system, interfering with
normal feeding (Loosanoff 1937). According to Loosanoff, when food was found
in the stomach contents of spawning fish, it **mainly consisted** of diatoms
and **dinoflagellates** with occasional copepods. Hart and McHugh (1944), however,
were able to catch ripe smelt in a dip net by attracting it with roe.

Predators

Many investigators (Bean 1887, Frey **1971,** Branson 1972) emphasize the im-
portance of surf smelt in the diet of salmon. In fact, Branson (1972) uses
the predation by salmon as a factor in explaining the uneven sex ratio of
surf smelt on the spawning grounds. He feels that since female surf **smelt**
school in deeper water than males, they are more accessible to predation
by salmon, and thus fewer females survive to spawn. In addition to salmon,

surf smelt are eaten by lingcod and striped bass (Frey 1971). They have also been found in the stomachs of fur seals caught off the coast of British Columbia and in the Gulf of Alaska (North Pacific Fur Seal Commission 1962), and they reportedly make up part of the diet of the beluga whale (Delphinapteras leucas) in the Okhotsk Sea and Gulf of Tatary (Kleinenberg et al. 1964).

<p style="text-align:center">Behavior-- Schooling and Migrations</p>

While not much is known about the life history and behavior of surf smelt between their hatching and their return to the beaches to spawn, they are believed to travel in schools (Loosanoff 1937, Branson 1972). Swan (1881a) cited an instance in which a steamer captain traveling between Point Grenville and Quillehute on the Washington coast came upon a school of smelt 40 miles in length.

Smelt migrate to the coast to spawn (Rass, Kaganovskii, and Klumov 1955), but the extent and direction of their movements vary with locality and are largely unknown.

POPULATION STRUCTURE AND DYNAMICS

The length distribution of surf smelt presented in Fig. 111.9.3 indicates there is a fair amount of variation in length between populations spawning at different 'locations. Variations in length frequencies can also be expected between samples taken at different times from the same location (Yap-Chiongco 1941) .

Stock size or relative abundance of surf smelt in the Gulf of Alaska have not been determined. Even in British Columbia and Puget Sound where commercial fisheries have been operating for many years, the fisheries statistics are considered too incomplete to be used as a reliable estimate of population size (Frey 1971).

The trend of the British Columbia catches, however, indicates a general decline in abundance since 1905 (see Fig. 111.9.4). A similar decline in smelt landings was noted in Puget Sound between 1920 and 1934 (Schaefer 1936). Hart and McHugh (1944) suggested that construction near beaches has eliminated some of the natural spawning areas. They also recommend that surf smelt be protected from fishing during part of their spawning season.

Although dead fish are seldom found on the spawning grounds, most investigators feel that many of the fish die soon after spawning (Loosanoff 1937, Yap-Chiongco 1941). While some females live to spawn in their third year, no four-year-old fish have yet been found, indicating mortality through natural causes or by the intense fishery.

In the past , native fisheries of the surf smelt seem to have been concen-
trated along the Olympic Peninsula where the Quillehutes and neighboring
tribes caught them in dip nets and strung them up to sun dry on strips of
cedar bark (Swan 1881a, Hart and McHugh 1944). Present day sport fisheries
still make use of the same type of dip net or smelt "rake" as well as two-man
jump nets (Leong 1967, Branson 1972). The commercial fisheries, which are
concentrated along the coast of British Columbia and in Washington State
use drag bag nets, beach seines, purse seines, and gill nets (Schaefer 1936,
Leong 1967, Hart 1973). Since the fishery focuses on spawning fish, it moves
from area to area according to the spawning seasons at the different locations
(Schaefer 1936). According to Schaefer , in the past there has been very
little escapement of the older fish from the commercial and sport fisheries,
indicating a need for some management of the resource.
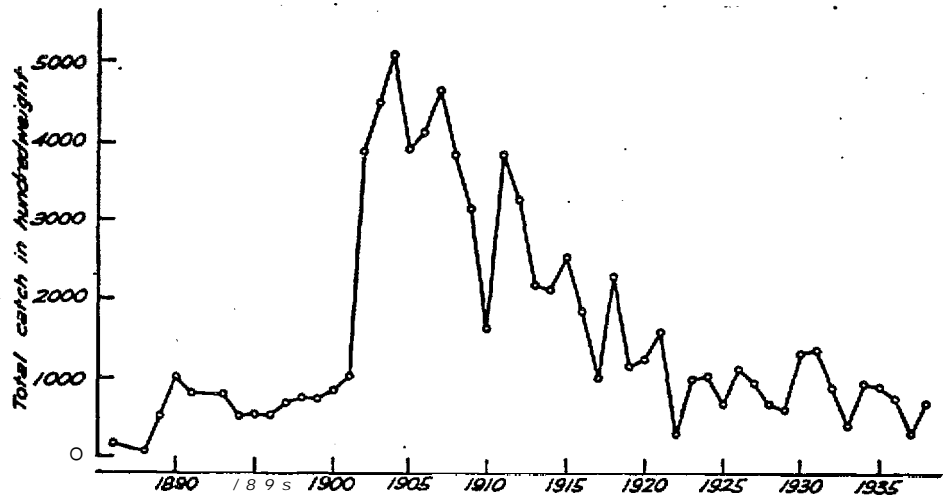
Figure 111.9.4.--Surf smelt catch statistics, British Columbia
   (from Hart and McHugh 1944).

CAPELIN (<u>Mallotus villosus</u>)
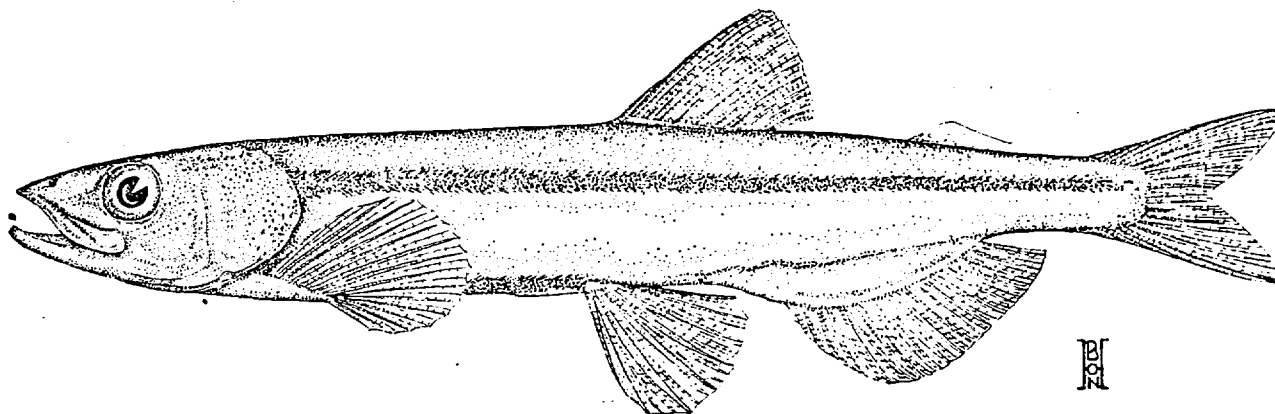
Figure 111.10.1.—Capelin, <u>Mallotus villosus</u> (from Hart **1973**).

IDENTIFICATION

'i'he **capelin,** like the-other smelts, has had a long history of taxonomic confusion, and as a result it has accumulated a fairly long list of synonymous scientific names (from Andriyashev **1954,** McAllister 1963):

<u>Clupea villosa</u> Müller 1776
<u>Mallotus villosus</u> Müller 1777
<u>Salmo arcticus</u> Fabricius 1780
<u>Salmo catervarius</u> Pennant 1784
<u>Salmo groenlandicus</u> Bloch 1793
<u>Salmo lodde</u> Lacepede 1804
<u>Clupea lodna</u> Hermann 1804
<u>Salmo socialis</u> Pallas 1814
<u>Osmerus microdon</u> Valenciennes 1848
<u>Mallotus elongatus</u> Mori 1930
<u>Mallotus catervarius</u> Schultz 1937
<u>Sudis squamosa</u> Chapman 1939
<u>Mallotus villosus catervarius</u> Rumjanzen 1947
<u>Mallotus villosus socialis</u> Berg 1948

As indicated from the names, in addition to having an uncertain relationship to the other smelts and to herring, **capelin** was once thought **to** be a member of the salmon family (Schultz 1937). For a time the Atlantic and Pacific **capelin** were thought to be separate subspecies, so the Atlantic (and nearby arctic) form was designated <u>Mallotus villosus villosus</u> and the Pacific form was called <u>**M. villosus socialis**</u> (Walters 1955). Other investigators felt differences in fin rays, lateral line scales, and gill arches warranted separate species status of these two forms (McAllister 1963). As exploration

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of the arctic continued, however, it was discovered that the distribution
of capelin is continuous across the Canadian arctic instead of being discon-
tinuous as was previously thought. Now only a single species, Mallotus villosus,
is generally recognized (McAllister 1963).

Because the capelin is such a widely distributed fish, it has a variety
of common names. It is called le capelan by the French, lodde by the Germans,
Norwegians, and Dutch, villaknore by the Finnish, and karafuto-shishamo
by the Japanese (McAllister 1963). In the U.S.S.R. , it may be known as tick,
moiva, salakushka, ouiki or uikey (Schultz 1937, Andriyashev 1954).

Mallotus villosus can be distinguished from other smelt species by the large
number of lateral line scales (170 to 200), the long base of the squared-off
adipose fin, and the small ninth pelvic ray (McAllister 1973). It is similar
in coloration to some other smelt species, being olive-green dorsally and
silvery on the sides and ventrally (Hart 1973), and it has the characteristic
smell of fresh cucumbers (Meek 1916). Spawning adults display a considerable
amount of sexual dimorphism. The males are generally larger and have a deeper
body than the females (Nikol'skii 1954). During the breeding season the
rays of the anal, pectoral, and pelvic fins of males become enlarged and
thickened (Trumble 1973). Special scales on either side of the lateral line
project so prominently that the fish becomes almost quadrangular in cross
section (Fraser 1915). In addition, long filamentous processes on the lateral
line-scales @ve these lateral ridges a distinctly hairy appearance
(Nikol'skii 1954). The spawning males also have a blunter snout, larger
fins, and small tubercles on the head, fin rays, and ventral surfaces
(McAllister 1963). Females have a more tapered body form and smaller fins
than the male (Hart and McHugh 1944).

DISTRIBUTION

General Distribution

The capelin, Mallotus villosus, is distributed over much of the Arctic,
North Pacific and Atlantic Oceans. Along the Atlantic coast of North America
it is found from Hudson Bay to Nova Scotia and   occasionally as far south
as the Penobscot River in Maine (Meek 1916,   McAllister 1973). It is found
near Greenland, Iceland, Norway, and along the northern U.S.S.R. coastline
to a latitude of 75°N in the Kara Sea.   although recent records indicate
the species to be circumpolar (Meek 1916, Walters 1955). On the Asian side
of the Pacific it is found in the Bering Strait, along the Kamchatka Peninsula,
in the Sea of Okhotsk, the Sea of Japan, and as far south at lat 40°N in
Korea (Schultz 1937, Berg 1948) (Fig. 111.10.2). As yet capelin has not
been found to occur along the northern coast of the U.S.S.R. from Bering
Strait to the Lena River delta, but it is thought that this may be due to
incomplete sampling (McAllister 1973). Along the coasts of North America,
Mallotus villosus ranges from across northern Canada to Point Barrow, Alaska,
and south along Alaska and British Columbia to the Strait of Juan de Fuca
in Washington (Berg 1948, Wilimovsky 1954, McAllister 1973). According to
Turner (1886) and Hart and McHugh (1944), the capelin is especially abundant
in the Bering Sea and along the Aleutian chain.
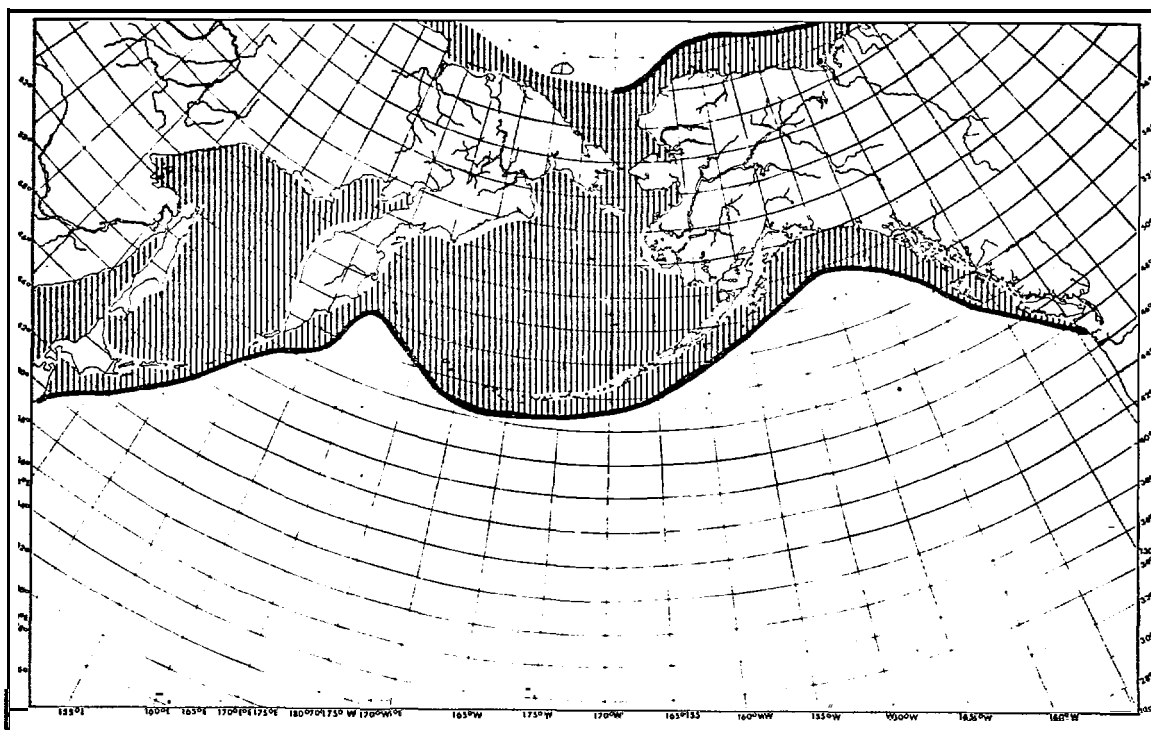
Figure 111.10.2 .--Distribution of **capelin** (from information in
   Schultz 1937, Berg 1948, Walters 1955, McAllister 1963, and
   Wilimovsky 1964).

Distribution in the Eastern Bering Sea and the Gulf of Alaska

Eggs and **larvae**

Because the eggs of the **capelin** are adhesive and **demersal,** they remain in
the vicinity of the spawning grounds. Kashkina (1970) mentions that **capelin**
eggs are distributed on the continental **shelf** in the Bering Sea over a wide
range of depths and out to some distance from the shore. Baxter (1975) gives
the location of some of the inshore spawning areas in Bristol Bay as shown
in Fig. III.10.3. In addition, a 1976 **memorandum** from Alaska Department
of **Fish** and Game cited by Warner (1976) indicated that **capelin** spawn along
the **northern** side of the Alaskan Peninsula at least as far east as Port
Heiden.

As spawning takes place in May and June in Bristol Bay (Baxter 1975), the
newly-hatched larvae are found in the **ichthyoplankton** of the Bering Sea
during the summer **(Kashkina** 1970). **Musienko (1963)** reported the existence
of a large concentration of **capelin** larvae in the Bering Sea southwest of
Cape **Newenham** in July 1958 (see map, Fig. 111.10.4). Smaller concentrations
were located south and east of the **Pribilofs** and **north of Unimak** Island.
By late August and early September, larvae were still found in the previously
mentioned regions, but they were distributed over a larger area somewhat

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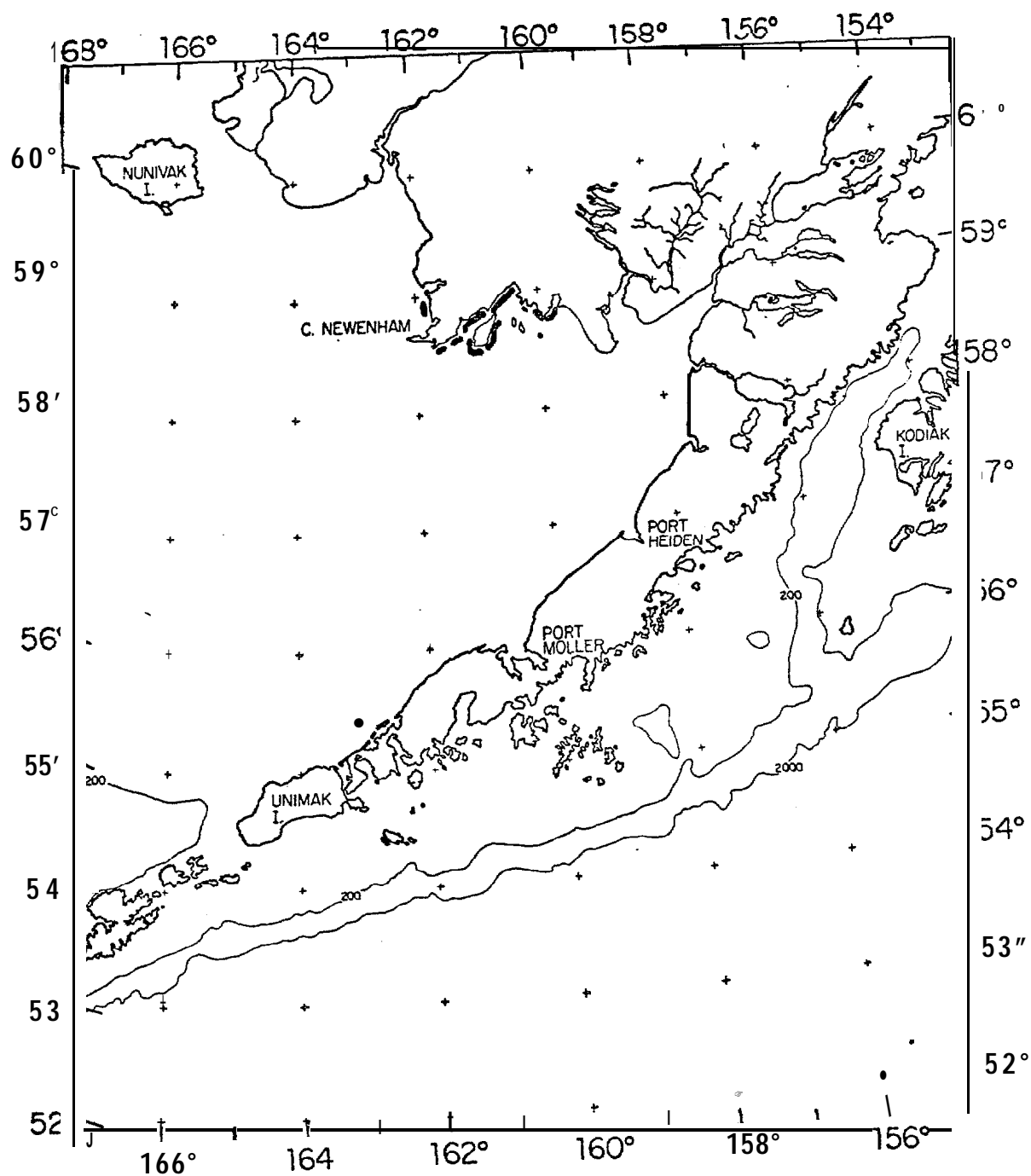
Figure 111.10.3. --Distribution of capelin spawning areas as shown by northern Bristol Bay survey, June 1975 (modified from Baxter 1975).

July 1958 U.S.S.R.", cruise

late August, early September 1958 U.S.S.R. cruises

A   July 1959-60 Japanese cruises (OSHORO MARU)
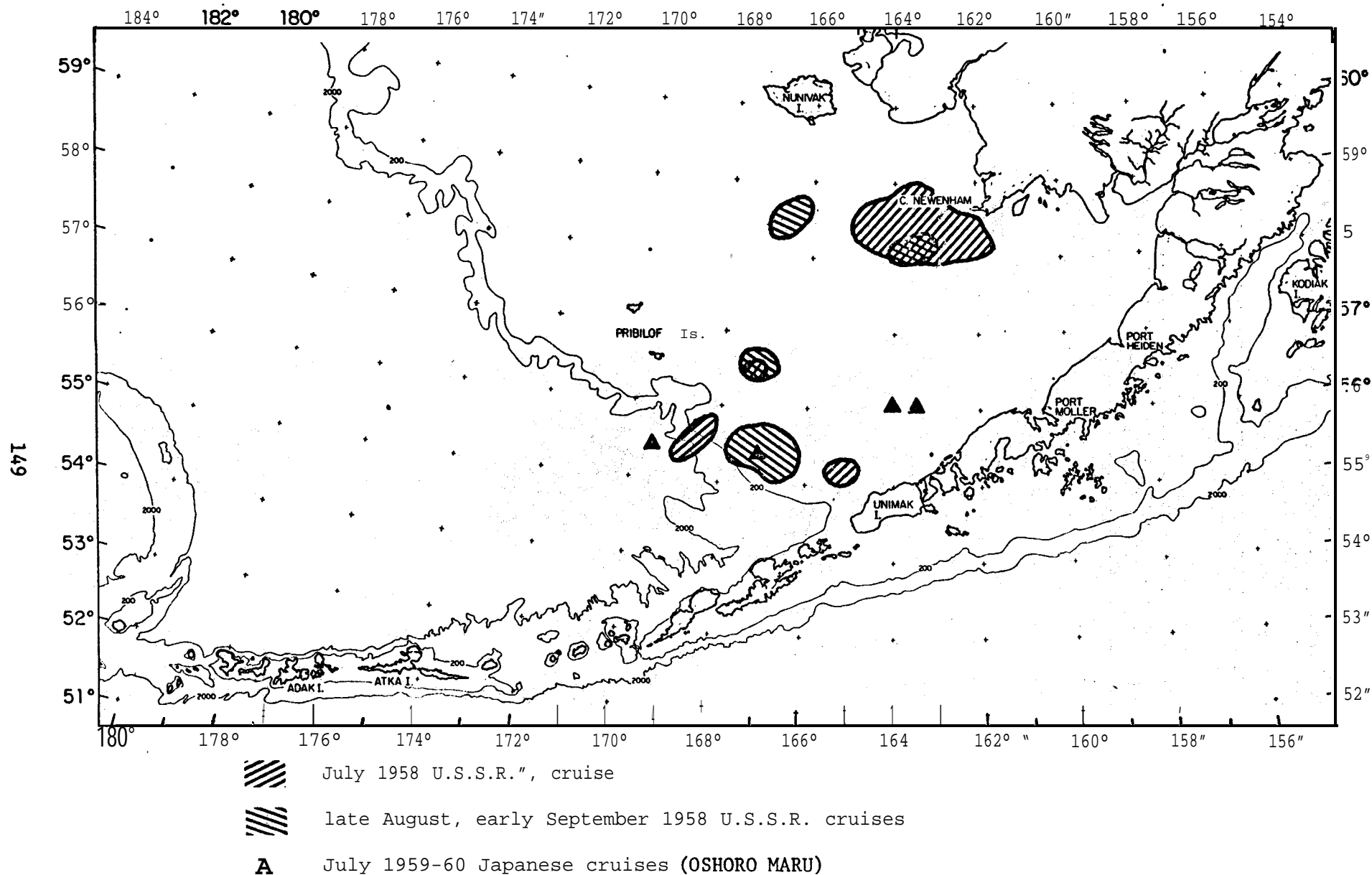
Figure 111.10.4 .--Location of capelin larvae collections from research cruises in the Bering Sea
    (from Faculty of Fisheries, Hokkaido University 1960, 1961a; Musienko 1963).

southeast of the Pribilofs and they also were found directly south of Nunivak
Island. These larvae, which were collected by the Soviet expedition, ranged
in length from 5.5 to 27.3 mm and were captured at depths of 25 to 375 meters
with a surface water temperature of 5.4 to 10.5OC and a bottom temperature
of 0.78 to 9.1°C (Musienko 1963). Capelin larvae were also found in Shelikof
Strait near Kodiak Island (Fig. 111.10.5).
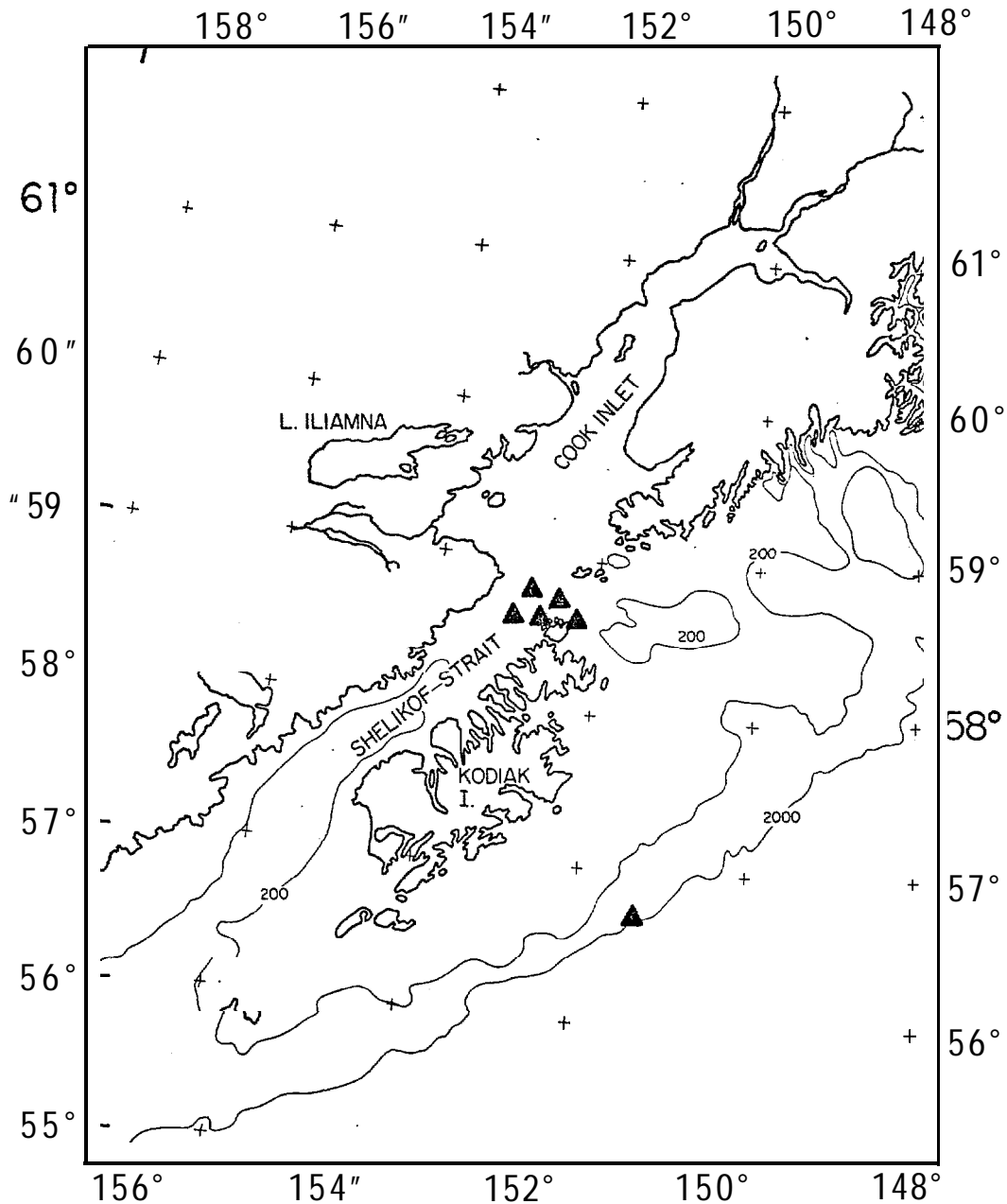
Figure 111.10.5.--Location of capelin larvae collections from the
University of Washington Brown Bear cruise of September 1957 in
the Gulf of Alaska (mapped from information given in Aron 1960a,b).

Adults

During most of the year <u>Mallotus villosus</u> is a bathypelagic fish, residing
in large schools near the bottom, often long distances from shore (Trumble
1973, Nikol'skii 1954), but in the spring or early summer the concentrations
move toward the shore and rise to the surface on their way to the spawning
grounds (Meek 1916). During this migration and throughout the breeding season,
it becomes a prime target of fur seals and other predators. From July to
October the vicinity of Unimak Pass becomes a favored feeding ground for
fur seals, which gather to consume vast quantities of capelin that are con-
gregated there at that time (Fig. 111.10.6) (Fiscus, Baines, and Wilke 1964).
Fur seals captured off Unalaska Island, south of the Shumigans, and east
of Kodiak also contained capelin in their stomachs, indicating other areas
in which capelin may concentrate (National Marine Fisheries Service 1970).

Most investigators agree that capelin spend most of the year in the ocean
depths (Meek 1916, Andriyashev 1954, Nikol'skii 1954), although Musienko
(1970) and Fedorov (1973a) indicate that at times capelin are found throughout
the water column. In the Gulf of Anadyr in the U.S.S.R., capelin were
primarily found at 65 to 74 meters (Andriyashev 1937), and capelin in Bristol
Bay were captured at 20 to 33 meters (Gilbert 1895).

Except during the-spawning season, capelin distribution seems to be associated
with relatively cold water temperatures (Trumble 1973). Capelin were most
frequently caught in trawls in the southeastern Bering Sea at temperatures
from 0 to -1°C (Shuntov 1963), and in the Gulf of Anadyr they were found
most abundant at temperatures of 1.3 to -1.7°C over clay and sandy bottoms
(Andriyashev 1937).   .

LIFE HISTORY

Reproduction

There has been some confusion about the age at which Pacific capelin reach
sexual maturity. Fraser (1915) noted that spawning capelin had only one
growth ring on their scales, thus indicating that they may be only one year
old. Later it was discovered that capelin scales do not begin to form until
10 to 12 months after spawning, thus no check would exist for the first
winter, making the spawning capelin observed by Hart and McHugh (1944) at
the. end of their second year and possibly at the termination of their third
year (Trumble 1973). Schultz (1937) first noticed that Pacific coast capelin "
reach sexual maturity at a much smaller size than Atlantic coast capelin.
He found that mature Pacific capelin ranged in length from 89 to 109 mm
standard length, while mature specimens from Newfoundland were 129 to 166 mm.
Hart and McHugh (1944) give the size range for spawning British Columbia
capelin as 94 to 115 mm for males and 90-to 112 mm for-females. As larger
capelin tend to mature earlier than smaller ones, the general size of spawning
capelin tends to decrease as the spawning season progresses (Trumble 1973).

AREA	OCCURRENCE
● MA LLOTUS VILLOSUS ●	
WESTERN ALASKA	81
UNIMAK PASS	258
BERING SEA	52
TOTAL	391
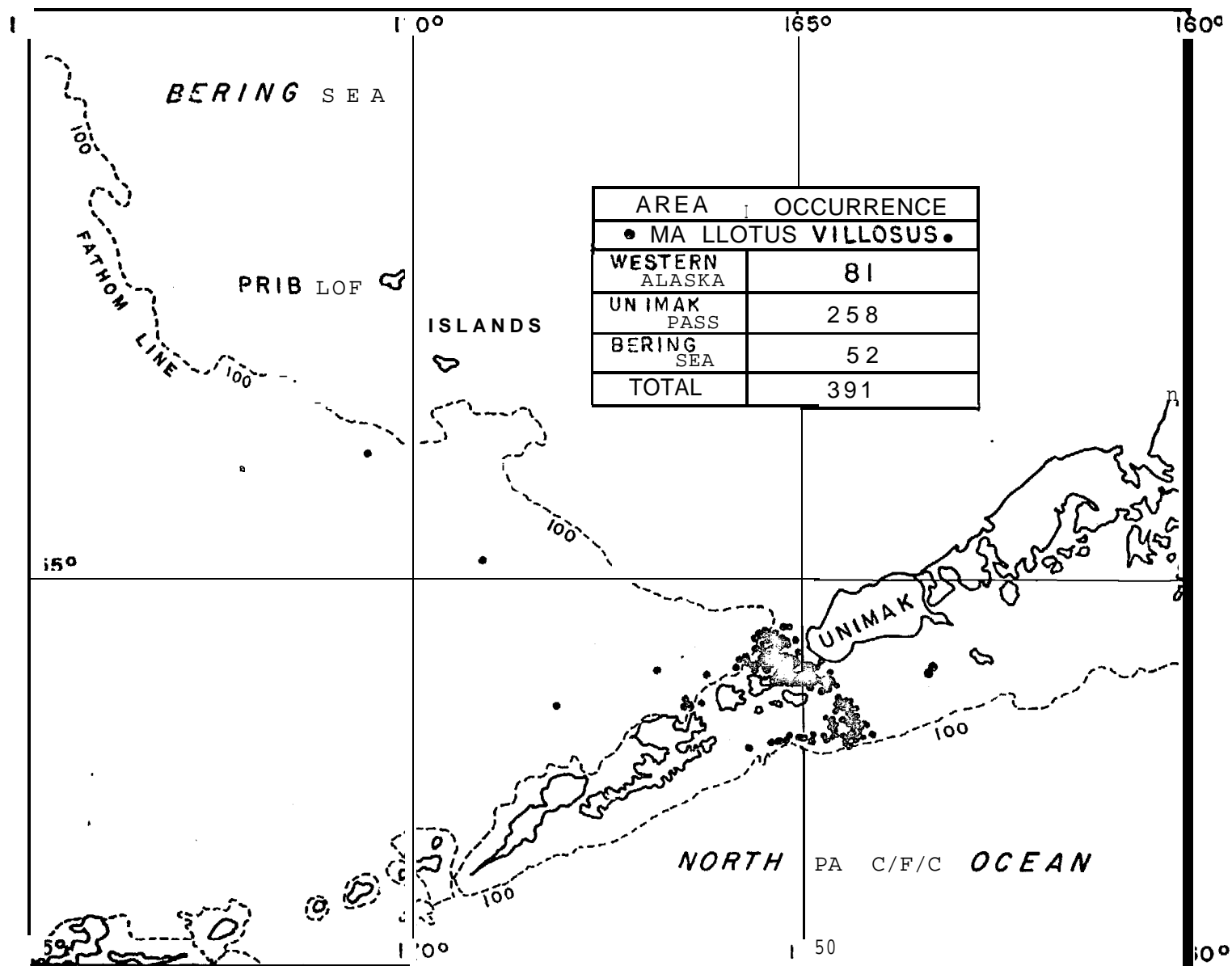
Figure 111.10.6 .--Locations in western Alaska where fur seal stomachs collected in 1962 contained capelin (Mallotus villosus) (from Fiscus et al. 1964).

Meek (1916) indicated that male capelin generally precede the females on the spawning grounds. Reports by later investigators (Walters 1955, Trumble 1973), however, seem to indicate that the predominance of males in the spawning area persists throughout the season and is due to a difference in local distribution. As is documented by cast net and seine catches, the males dominate the inshore areas while the females and immature males congregate in the deeper water further offshore (Trumble 1973). There is a wide variation in fecundity of the capelin depending on geographical location. While British Columbia capelin range in fecundity from 3,0.20 to 6,670 eggs per female (Hart and McHugh 1944), capelin from the Barents Sea lay from 4,581 to 22,021 eggs (Trumble 1973), and those from the Sea of Japan produce 15,000 to 57,000 eggs (Andriyashev 1954). The high fecundity in some areas is thought to be due to the larger size of the spawning fish (Hart 1973).

. The known spawning areas of the capelin in Bristol Bay, Alaska, have been presented previously in Fig. III.10.3. In addition, capelin spawn along the northern side of the Alaska Peninsula (Warner 1976), in the northern Bering Sea (Andriyashev 1954), and in southeastern Alaska (Marsh and Cobb 1908). Some capelin spawn along the British Columbia coast as far south as Ladysmith on Vancouver Island (Hart and McHugh 1944).

According to Hart"and McHugh, a Particular type of substrate is selected by the spawning fish. Rocky areas are avoided, and beaches having sand grain sizes of 0.04 to 0.2 mm seem to be preferred (Hart and McHugh 1944). Salinity also seems to be an important factor in the local distribution of spawning areas, capelin seeming to prefer areas of high salinity. Walters (1955) felt that the low salinities along part of the Siberian coast might explain why capelin have not been found there.

The spawning season varies with the geographical location and with the oceanographic conditions. On the Asian side of the Bering Sea (see Table 111.10.1), the southern populations appear to spawn first, and the northern fish spawn

Table 111.10.1 .—Spawning dates of capelin in various areas of the Pacific.

Are a	Time	Source
Asian side		
Peter the Great Bay	April-May	Nikol'skii 1954
Sea of Okhotsk	May-July	Nikol'skii 1954
Kamchatka	June	Nikol'skii 1954
Gulf of Anadyr	June-July	Musienko 1970
North American side		
Point Barrow	end of July-Aug.	Andriyashev 1954
Bristol Bay	May 30-June 15	Baxter 1975
Sitka (S.E. Alaska)	October	Marsh and Cobb 1908
Strait of Georgia	late Sept., Oct.	Hart and McHugh 1944

later as the waters warm (Hart and McHugh 1944; Rass, Kaganovskii, and Klumov
1955; Trumble 1973). However, on the United States and Canadian side of
the Pacific, spawning occurs in Bristol Bay in June and in the Strait of
Georgia in September or October, seemingly contradicting the rule. The water
temperature during spawning ranges from 10 to 14°C for eastern Pacific capelin
(Hart and McHugh 1944).

Generally, about a month before the spawning season begins, the capelin
begin to congregate in the offshore waters at 50 meters depth or less (Trumble
1973). The actual spawning takes place primarily at night or on heavily
overcast days. Activity is greatest just after high tide, especially when
the surf is high (Trumble 1973). Two males accompany a female toward the
beach, pressing the body of the female between them in the pocket formed
by the overhanging spawning ridges of the males. The eggs and spawn are
expelled and the fertilized eggs are buried in the sand by the waves at
about the 10 to 12 foot (3.05 to 3.6 meter) tide level (Thompson et al.
1936, Hart and McHugh 1944). This process is repeated until all of the ripe
eggs have been spawned, after which the female returns to deeper waters
offshore, but the males remain to fertilize other females (Trumble 1973).
According to Trumble, the size frequency of ovarian eggs indicates that
more than one batch of eggs may be spawned in a given season, but it is
not known whether this actually occurs.

In addition to beach spawning in shallow water, capelin have also been
observed to spawn as deep as 100 meters in the Barents Sea, and it is possible
that deep-water spawning may also occur in" Alaskan waters, as beach spawning
does not occur every year in some areas (Walters 1955).

The eggs, ranging from 1.0 to 1.1 mm, in diameter, are adhesive and form
masses which in turn stick to the gravel or sand substrate (Thompson et al.
1936, Musienko 1970). The particle size of the substrate is thought to be
a factor in the proper aeration of the developing eggs (Hart and McHugh
1944).

Growth and Nutrition

Growth

The relationship of hatching time and temperature is fairly well known for
capelin in the western Atlantic. At 5°C, eggs hatch in 30 days; at 10°C,
eggs hatch in 15 days; and at 15°C, eggs hatch in 8.5 days (Trumble 1973).
Musienko (1970) reported the hatching of capelin larvae in the Bering Sea
in about 15 days at 100c. After emerging from the egg, the transparent larvae,
about 8 to 10 mm in length (Meek 1916), are washed out of the sand by the
waves and carried out to sea (Turner 1886). Although little is known about
the development of the larvae once they arrive in the ocean depths, Nikol'skii
(1954) reported that Bering Sea larvae have a much more rapid growth rate
than those from the Atlantic. Most growth in length and weight occurs within
the first two years (Musienko 1970), thus second or third-time spawners
may be difficult to distinguish from first-time spawners on the basis of
length alone. Male capelin grow to a larger size than females, but usually
most of this differential growth occurs after the first year (Nikol'skii
1954, Jangaard 1974). Schultz (1937) reported that the standard length of

Pacific capelin ranged from 89 to 109 mm, with an average length of 95.8 mm.
Baxter (1975), however, found the lengths of four" Bristol Bay specimens
were somewhat larger, ranging from 110 to 146 mm, with an average of 130.2 mm.
According to Andriyashev (1954), capelin can reach a size of 220 mm, but
they generally are between 140 and 180 mm in length.

Food and feeding

The Pacific capelin feeds primarily on small crustaceans such as euphausiids,
cumaceans, decapod larvae, hyperids, and calanoid and harpacticoid copepods
(Andriyashev 1954). Capelin have also been known to consume marine worms
and small fish (Hart 1973). It is not known whether capelin are selective
feeders because no comparisons have been made between stomach contents and
the composition of the plankton (Trumble 1973).

We assume that capelin in the North Pacific Ocean have a highly seasonal "
character of feeding similar to that documented by Winters (1970) for the
Atlantic Ocean. In the Atlantic Ocean, during the overwintering period there
is a low feeding rate but the fat content is fairly high. In the pre-spawning
period (April to May near Newfoundland), there is a great increase in the
feeding rate as the gonads develop and the fat content drops. When the
spawning season begins the capelin stop feeding and the fat content is quite
low, so that by the time the fish arrive at the spawning grounds they are
fairly emaciated.

Predators and Competitors

The capelin is an important link in the food chains of the North Pacific
and Bering Sea. Salmon, cod, and coalfish feed extensively on capelin; 40
of the small fish were found in the stomach of one cod taken off Portlock
Bank (Bean 1887, Meek 1916). Dogfish are often present in the area during
spawning and have been observed chasing capelin up the beach (Fraser 1915,
Hart and McHugh 1944). An arctic charr was caught at Point Barrow which
also contained capelin (Walters 1955). Marine mammals such as hair seals,
fur seals, bearded seals, harbor seals, sea lions, Dan porpoises, killer
whales, and balaenoptera whales are all known to consume capelin (Turner
1886, Meek 1916, Geptner et al. 1976). The importance of capelin in the
diet of fur seals is illustrated in Fig. 111.10.7 which shows that, by volume,
capelin composed 56.8% of the stomach contents of fur seals captured in
Alaskan waters in 1962 (Fiscus et al. 1964). During other years, capelin
have made up as much as 90% of the stomach contents of pelagic fur seals
(Taylor, Fujinaga, and Wilke 1955). In addition to the fish and marine mammal
predators, aquatic birds such as gulls and terns attack the migrating fish
when they swim near the surface (Turner 1886).
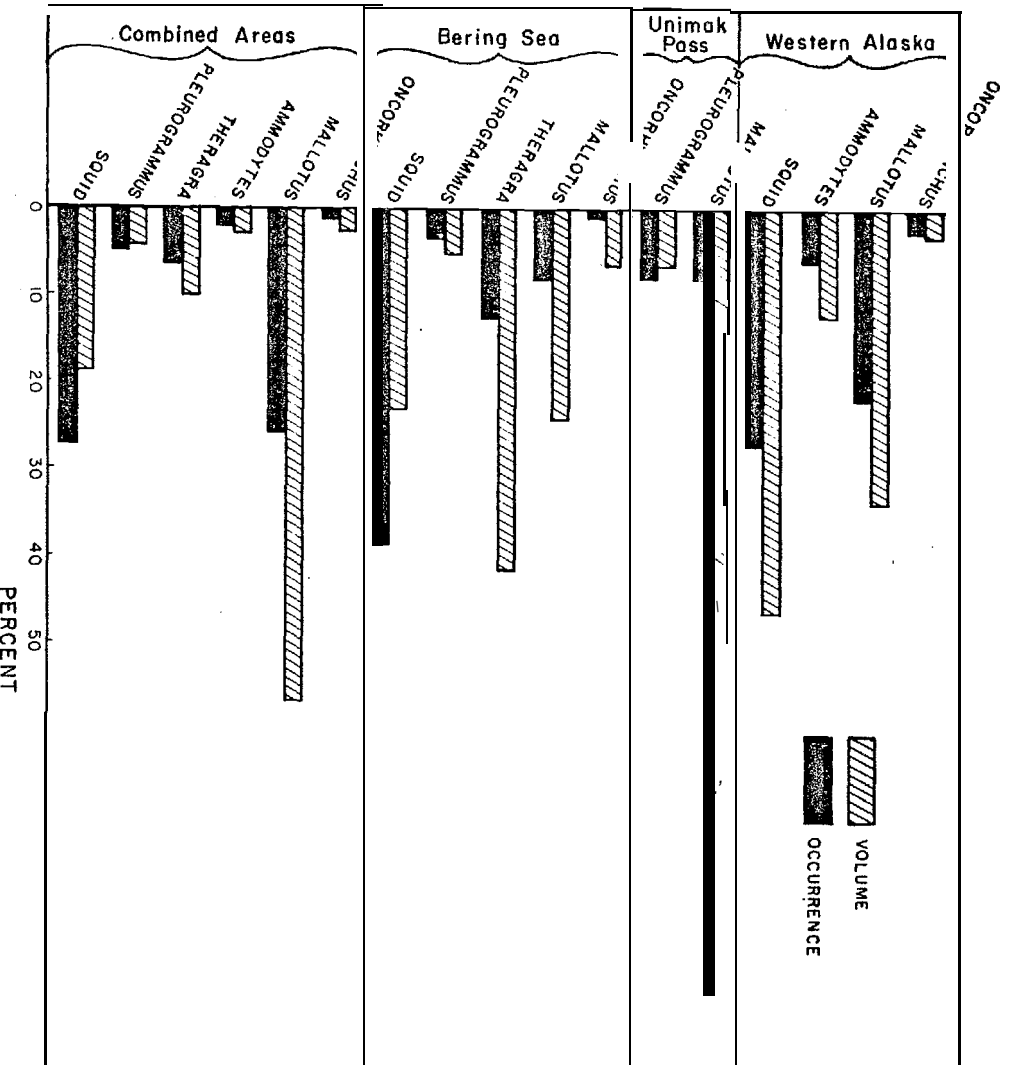
Figure III.10.7.—Stomach contents of fur seals captured in 1962, by area. Principal food species are given in percent volume and percent frequency of occurrence (from Fiscus et al. 1964).

Parasites and Diseases

Not much is published on the parasites and diseases of Pacific capelin, but capelin in the Atlantic are infected with a nematode Contracaecum which affects 26 to 81% of the stock at certain times of the year (Winters 1970, Jangaard 1974). Fraser (1915) also mentioned that many of the spawning capelin in British Columbia were "battered up and diseased."

Behavior

There are indications that capelin school throughout much of their life. According to Trumble (1973), overwintering fish form large congregations near the bottom in deep water; in early spring, these large shoals break up into smaller schools which move off the bottom to feed. As the spawning period approaches, the capelin migrate to the coast where they segregate by sex, the males schooling closer to the shore. Juveniles form separate schools from the adults and remain in deeper water when the mature fish move in to spawn.

As with other smelts, the migration of **capelin** is seasonal. Larvae are carried out to sea soon after they have hatched, and they spend most **of** their early life in deep water **(Musienko** 1970). **In** the spring of their first year, **the** immature fish migrate to the inshore areas with the mature adults. They stay in offshore water with the **pre-spawning** females **until** the spawning season is over before returning **to** the ocean depths with the surviving spawners **(Trumble** 1973). The distance of the pre-spawning migration is quite variable. Off eastern Canada the distance may be quite short, but in the northeastern Atlantic and probably in the northeastern Pacific much longer distances are involved **(Trumble** 1973). Rass et **al. (1955)** observed that **capelin** migrations may also be influenced by the winter and spring hydro-meteorological **conditions.** In response to cool periods, **capelin** may **migrate** to the southern limit of their distribution , and warming temperatures may stimulate a movement to more **northernly** locations **(Rass** et al. 1955). Inshore movements are usually accompanied by an ascension into the upper water layers (Meek **1916, Nikol'skii** 1954).

POPULATION STRUCTURE AND DYNAMICS

Although the sex ratio of males to females on the spawning beaches indicates a predominance of males during most of the spawning season, this difference may be due entirely to the separate schooling of the non-spawning females offshore. Slightly more males than females were caught among Atlantic **capelin** feeding schools, but this difference was not significant **(Trumble 1973).** As little information on sex ratios of non-spawning Pacific **capelin** populations is **available, the** sex composition is unknown at present.

The size composition varies with location and the length of the dominant year class **(Trumble** 1973, Jangaard 1974). Hart and McHugh (1944) noted that the **capelin** spawning along the British **Columbian** coast were all about the same size and concluded that they were all of the same year **class.** Because some **capelin** are repeat spawners, however, several age classes must be represented even though the **length** frequencies may be similar.

Early explorers to the Alaskan territory remarked about the extreme abundance of **capelin,** especially along the Aleutian Islands and in **Norton** Sound (Turner 1886, Nelson 1887, Jordan and Gilbert 1899, Meek 1916). The abundance of the spawning fish seems to vary from year to year on a cyclical basis, however. Turner (1886) remarked that **capelin** appeared to be numerous on Attu and Atka only every third year. A similar yearly fluctuation seems to have taken place among some of the Atlantic **capelin** stocks where every five years an exceptional abundance was noted (Meek **1916).** Due **to** the paucity of statistics on this species, no reliable estimate of the abundance in the Pacific can be made, but the high incidence of **capelin** in fur seal stomach contents indicates that the population may be quite large.

Post-spawning mortality of **capelin** is very high. According **to Rass** et al. (1955), approximately **90%** of the fish die soon after the first spawning. Mortality is especially heavy if the surf is high, for fewer of the exhausted **capelin** are able to regain the depths **and are** carried **ashore** (Thompson et al. 1936).

FISHING

Although at present there is little subsistence fishing of capelin (Baxter 1975), in the past great quantities of the small fish were caught and air dried either on ropes of twisted grass or on straw mats on the ground (Turner 1886, Schultz 1937). Recreational fishing now has taken the place of some of the native fisheries—the amateur sportsmen gathering the fish with buckets, home-made dipnets, garden rakes or even bare hands (Hart and McHugh 1944). In recent years, the Soviets have increased their capelin catch in Russian waters (Trumble 1973) and have shown some interest in developing a capelin fishery in the Bering Sea (Musienko 1963, Kashkina 1970, Fedorov 1973a). Beach seines, purse seines, and trap nets are used in the Barents Sea to catch these fish, which are then used mainly to bait trawl lines (Nikol'skii 1954). Capelin is also fished commercially in the Atlantic, both off eastern Canada and near the European coast (Trumble 1973), but at present no large-scale commercial fishing exists in the northeast Pacific.

POTENTIAL CONTRIBUTION TO DOMESTIC AND INTERNATIONAL ECONOMY

Pacific capelin is considered one of the presently underutilized resources which has definite possibilities for future development (Hart 1973). A trial sample was taken a few years ago in Bristol Bay, and a commercial operator stated that he thought the fish might be worth two to three cents per pound if an annual supply of a million pounds or more could be assured (Baxter 1975). In the northeast Atlantic Ocean, Norway and Iceland land over one million tons of capelin per year and the resource shows no sign of depletion, so by analogy a commercial fishery in the Pacific might have a chance of success even if the resource is only one-half to one-quarter that of the Atlantic. Even if the capelin is not caught for human consumption directly, its importance as a forage species for commercially valuable fish cannot be denied.
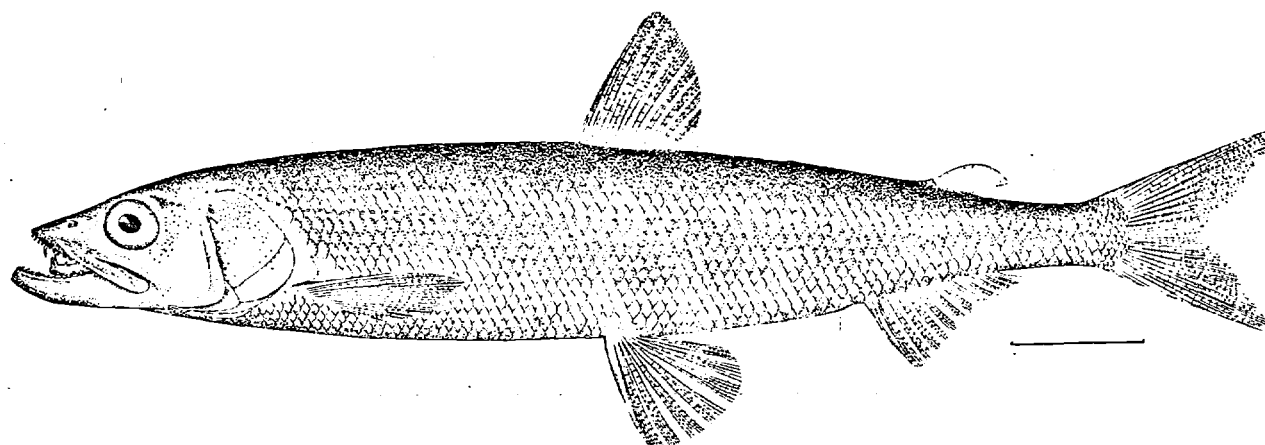
Figure **III.11.1.**--Rainbow smelt, <u>Osmerus mordax</u> (from Turner 1886).

IDENTIFICATION

As with other smelt species, the rainbow smelt has gone through a long history of taxonomic confusion. It is generally recognized that there are three main populations of <u>Osmerus:</u> one in Europe; one in northeastern North America; and one in the Arctic and Pacific Ocean waters of North America and Asia (McAllister 1963). Some investigators have accorded all three groups separate species status, others have felt that some were subspecies, and still others have suggested that all three be grouped together as the <u>Osmerus</u> <u>eperlanus</u> complex (Scott and Crossman 1973). As a result of the uncertain systematic standing of the Pacific form, various combinations of scientific names have been applied (adapted from Scott and Crossman 1973):

<u>Salmo eperlanus</u>
<u>Atherina   m o r d a x</u>
<u>Osmerus</u> <u>viridescent</u>   .
<u>Osmerus</u> <u>eperlanus</u>
<u>Osmerus</u> <u>mordax</u>
<u>O smerus</u> <u>sergeanti</u>
<u>Osmerus</u> <u>dentex</u>
<u>Osmerus</u> <u>spectrum</u>
<u>Osmerus</u> <u>eperlanus</u> <u>dentex</u>
<u>Osmerus</u> <u>eperlanus mordax</u>
<u>Osmerus</u> <u>mordax dentex</u>

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For the purposes of this report, the system proposed by Klyukanov in 1969 (cited by' Scott and Crossman 1973) and later accepted by Scott and Grossman and by Hart (1973), is used. Thus the Pacific and Arctic form is referred to as Osmerus mordax dentex, the North American Atlantic fish is Osmerus mordax mordax, and the European osmerid is Osmerus eperlanus. "As certain information on the life history of the Pacific rainbow smelt is limited, on occasion data are supplied from studies of the Atlantic subspecies.

The rainbow smelt has an elongate, fusiform body with the greatest depth anterior to the dorsal origin (Scott and Crossman 1973). Its general body color shades from olive on the back to a silvery belly, but on the sides a series of lateral bands of iridescent purple, blue, and rose, each shade into the next band of color (Nelson 1887). This species displays some degree of sexual dimorphism. The males are generally darker, have punctate oper- culum, and the paired and anal fins are usually larger than those of the females (McAllister 1963). In addition, during the spawning season the males develop large nuptial tubercles on the body scales and smaller tubercles on the head and on the leading rays of some of the fins (McAllister 1963). Rainbow smelt are known for having a pronounced odor somewhat similar to that of freshly cut cucumbers, and for this reason they are often called cucumber fish (Scott and Grossman 1973). Other common names are leefish, frostfish, arctic smelt, boreal smelt, and simply "smelt" (McAllister 1963, Bailey et al. 1970, Scott and Crossman 1973).

DISTRIBUTION

The Pacific rainbow smelt was reported by Turner (1886) to inhabit the waters near Saint Michael in Norton Sound. In 1887, Nelson observed that it was abundant from Kotzebue Sound (just north of the Bering Strait) to Kuskokwim Bay (long 60°N, lat 163°W). Subsequently its range was found to extend from Cape Bathurst in Arctic Canada to Point Barrow in Alaska, and south along the western coast of Alaska to Bristol Bay (Andriyashev 1954, Walters 1955). It is also said to be found in the Gulf of Alaska as far east as Yakutat Bay, in southeast Alaska, and in Barkley Sound on the west coast of Vancouver Island (Hart 1973). Walters (1955) reports the rainbow smelt is distributed from the White Sea in Arctic Europe along the northern and eastern U.S.S.R. coasts to Hakodate in Japan and to Chinnampo in Korea.

Distribution in the eastern Bering Sea and in the Gulf of Alaska

As Osmerus mordax eggs' are demersal and adhesive, they are found only at the spawning grounds which may be a river bottom, a land-locked lake, or the littoral part of a bay (Berg et al. 1949). Soon after hatching, larvae in rivers migrate to the sea where they can be found close inshore near the mouth of the river or along sand or gravel beaches (Scott and Crossman 1973). Juveniles are found offshore in the same area as the adults (Belya- nina 1969).

The distribution of the adult rainbow smelt is dependent on the stage in the reproductive cycle and thus the time of the year. During the non-spawning period the anadromous smelt can be found in the brackish waters of estuaries and bays. At this time they may occasionally enter the mouth of a river on a flood tide, but they leave with the next ebb (Rass, Kaganovskii, and

Klumov 1955). During the spawning season (generally spring to early summer),
river spawners enter rivers and swim upstream to a suitable spawning ground,
returning to the marine environment after spawning. A secondary spawning
run occurs in the autumn or early winter in some localities (Rass et al.
1955) ,

Fedorov (1973a) reports that the preferred habitat of the rainbow smelt is
the neritic zone where they may be found at depths ranging from the surface
to 120 meters. Gilbert (1895) noted that smelt were captured with a seine
at the 12 fathom (21.95 m) depth in Bristol Bay. Rass et al. (1955) found
that smelt in the Anadyr Gulf in the U.S.S.R. seem to prefer the 4 to 5
meter depth. Landlocked smelt in the Great Lakes region apparently have
different habits, however, for Ferguson (as reported in Scott and Crossman
1973) noted that during the day most rainbow smelt are found at or near
the bottom at depths of 80 feet (24.4 m) or more.

As Osmerus mordax is a cold-water species, its spawning habits and its usual
preference for relatively shallow inshore waters may limit its distribution
to arctic and temperate waters. The body length and relative abundance of
rainbow smelt decreases from north to south in its geographic range (Rass
et ale 1955).

LIFE HISTORY

Reproduction

There is a wide variation in the age at which sexual maturity is reached
(Belyanina 1969). Most rainbow smelt mature at the age of two or three,
but Belyanina found in many of the northern bays and rivers of the U.S.S.R.
the first spawning may not take "place until the fish is three or four years
old or even older. The size and weight at maturity varies correspondingly
(see Table 111.11.1).

Table 111.11.1.—Size and weight at maturity (first spawning season) in
    various U.S.S.R. smelt populations (modified from Belyanina 1969).

Locality	Length (cm)	Weight (g)	Authority
Rybinsk Reservoir	6.0-9.0	1.9-6.2	Lapin 1955-56
White Lake	6.0-8.5	1.5-3.5	Schetinina 1954
Ilmen Lake	4.7-8.2	1.1-4.3	Domrachev & Pravdin 1926
Lazmiaden Lake	9.3-11.8	5.1-8.5	Willer 1926
Kurishes Haff	6.3	1.4	Marre 1931
Ladoga Lake	8.0-11.0	3.3-8.7	Arkhiptseva 1956
Onega Lake	8.8-10.6	3.7-6.1	Stefanovskaya 1957 and others
Elbe River	16.5-18.2	abt. 17	Lillelund 1961
White Sea	18.8-22.6	41.7-75.5	Belyanina 1969
Ob River	18.3-19.3	42.5-48.5	Amstislavsky 1959
Yenisey River	20.3-22.3	51.2-68.0	Tyurin 1924 and others
Lena River	19.6-23.4	53.0-94.0	Priozhnikov 1950
Upper Lake	14.0-16.0	17.0-25.5	Bayley 1964

The sex ratio on the spawning grounds appears to change with time. Observations of White Sea smelt indicate that females outnumber males by 7 to 3 at the beginning of the spawning season, at the height of the spawning the ratio approaches 1:1, and near the end males predominate over females by 9 to 1 (Belyanina 1969). Investigators at other localities have found different patterns of sex ratio variation. McKenzie (1964) noted a greater percentage of males both at the start and end of the spawning season in the Miramichi River in New Brunswick, Canada. He also found that male smelt often stayed in the shallow waters of the spawning area throughout the day while the females entered the area only at night, retiring to nearby deeper waters during the day.

Berg et al. (1949) stated that the size and age of the female directly affects the fecundity, and this is corroborated by the work of Belyanina (1969.) ` as shown in Table 111.11.2. In addition, fecundity seems to vary with the locality because smelt from the Ob River produced only 350 eggs per gram of body weight while smelt from a lake near Leningrad (Pskovsko-Chudskoye) produced as much as 1,050 per gram (Belyanina 1969). Thus, fecundity may range from 8,500 to 69,600 eggs per female (Rass et al. 1955, McKenzie 1964). Unfortunately, no information on the fecundity of Osmerus mordax in the Gulf of Alaska or Bering Sea could be located.

Table 111.11.2.--Fecundity (thousands of eggs) of female rainbow smelts of the same sizes but different ages (White Sea smelt, original data) (Belyanina 1969).

Length (cm)	Age groups					
	3		4		5	
	Average	Min.-max.	Average	Min.-max.	Average	Min.-max.
19.0-19.9	37.6	25.6-44.5.	42.0	37.1-50.0	--	--
20.0-20.9	53.0	45.5-61.0	53.2	40.7-66.3	--	--
21.0-21.9	52.8	.-	62.1	43.9-83.8	--	--
24.0-24.9	--		88.6	87.7-90.0	95.5	88.8-102.3

Most rainbow smelt spawn only once a year in the spring, usually sometime between April and June, depending on the latitude the locality, and climatic conditions (Rass et al. 1955). For a given stream, the spawning time is quite regular from year to year, minor variations in schedule being due to storms, bright moonlight, or extended ice-cover, all factors which may delay spawning somewhat (Belyanina 1969, Scott and Crossman 1973). In some areas such as the Okhotsk Sea and the Shantarskii Islands, smelt make a second spawning run in the fall, around October or November (Rass et al. 1955), while some Siberian smelt do not spawn every year (Belyanina 1969).

According to Turner (1886), rainbow smelt. form large schools as they approach the shore and swim along it. They normally enter the rivers or bays at high tide soon after the ice breaks up when the water temperature is 3.5° to 10°C, but they sometimes enter rivers under the ice and have even b e e n known to spawn under an ice cover (Belyanina 1969). The spawning area may be in a river, where it usually is 2 to 20 km from the mouth, or in areas of a bay having low salinity (Berg et al. 1949). The typical spawning ground has a stony or pebble bottom and a current with a velocity of 0.3 to 2 m per second according to Belyanina. Osmerus mordax does not even enter streams having sluggish currents and muddy bottoms (Rass et al. 1955).

Spawning takes place at night, and the older and larger individuals spawn first (McKenzie 1964, Belyanina 1969). One or more tuberculated males maintain positions above and a little ahead of a spawning female, releasing milt as the female extrudes the eggs (Belyanina 1969, Scott and Grossman 1973). The eggs are deposited on t'he stones and underwater vegetation at depths of 2 to 6 meters in most areas and down to 17 meters in some Karelian Lakes (Rass et al. 1955, Belyanina 1969). In most locations, spawning lasts about a month, but the peak of spawning activity may encompass only two to four days (Belyanina 1969). Toward the end of the season, the average length and age of the spawning fish decreases; these late spawners usually leave before the water temperature reaches 15°C (Scott and Grossman 1973, Belyanina 1969).

The eggs, which become adhesive shortly after being extruded, attach to the substrate. Part of the adhesive outer coat forms a stalk upon which the egg sways in the current; the rest of the outer coat is pulled off the egg by the force of the current (Scott and Crossman 1973). According to Belyanina, the eggs (exclusive of stalks) are-round or slightly oval and are yellowish-white to yellow in color. Unfertilized eggs are semitransparent and contain many oil droplets. Berg (1948) gives the diameter of the egg as being from 0.86 to 1.03 mm, while other investigators have reported them as being 0.9 to 1.0 or 1.1 mm in diameter (Berg et al. 1949, Andriyashev 1954, Musienko 1970).

Nutrition and Growth

Growth

Embryonic development of White Sea smelt was described by Belyanina (1969) from Unanyan and Soin and is pictured in Figs. 111.11.2, 111.11.3. The length of the incubation period varies inversely with the water temperature and with different rainbow smelt populations (see Table 111.11.3). Hatching . may take place after 8 to 27 days (McAllister 1963), after which the young larvae drift swiftly downriver to a lake or estuary.

Growth is fairly rapid, and within a few months the slim, transparent larvae may reach 20 to 40 mm long (Scott and Crossman 1973). Females grow more rapidly than males, are larger at maturity, and frequently live longer (Rass et al. 1955, Scott and Crossman 1973). The rate of growth of various smelt population is given in Table 111.11.4. The average and maximum length of smelt also varies with locality. Landlocked rainbow smelt are generally smaller
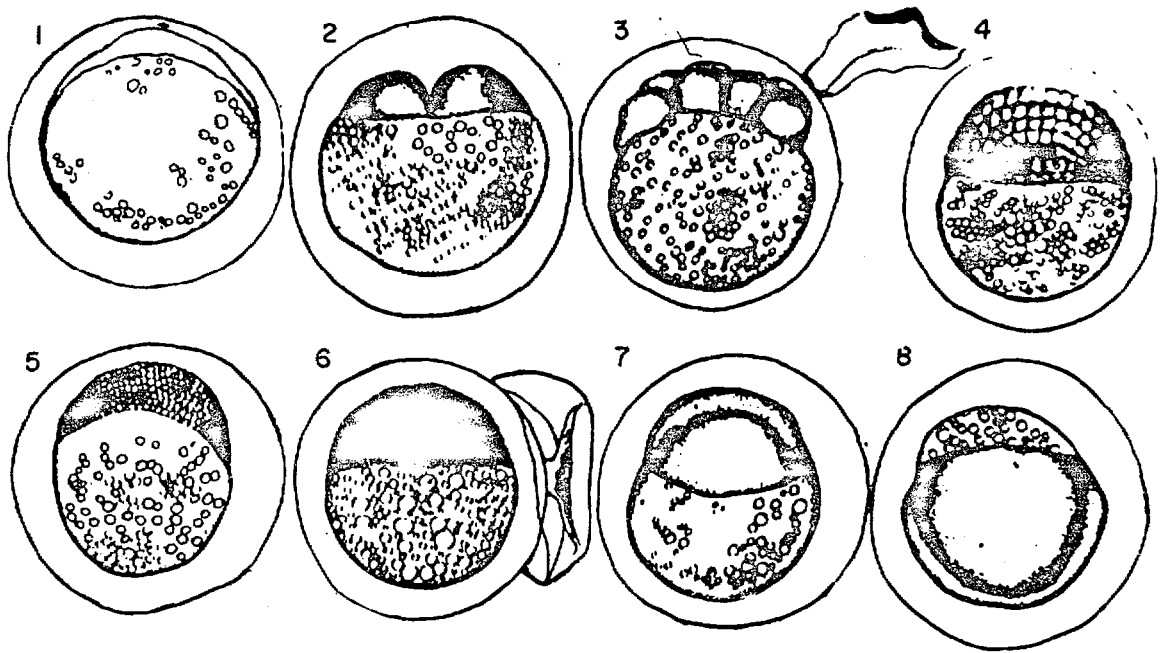
Figure 111.11.2.--Early stages of development of eggs of
the White Sea rainbow smelt (to the end of gastrulation).
(Taken by Belyanina 1969 from Unanyan and Soin 1963).
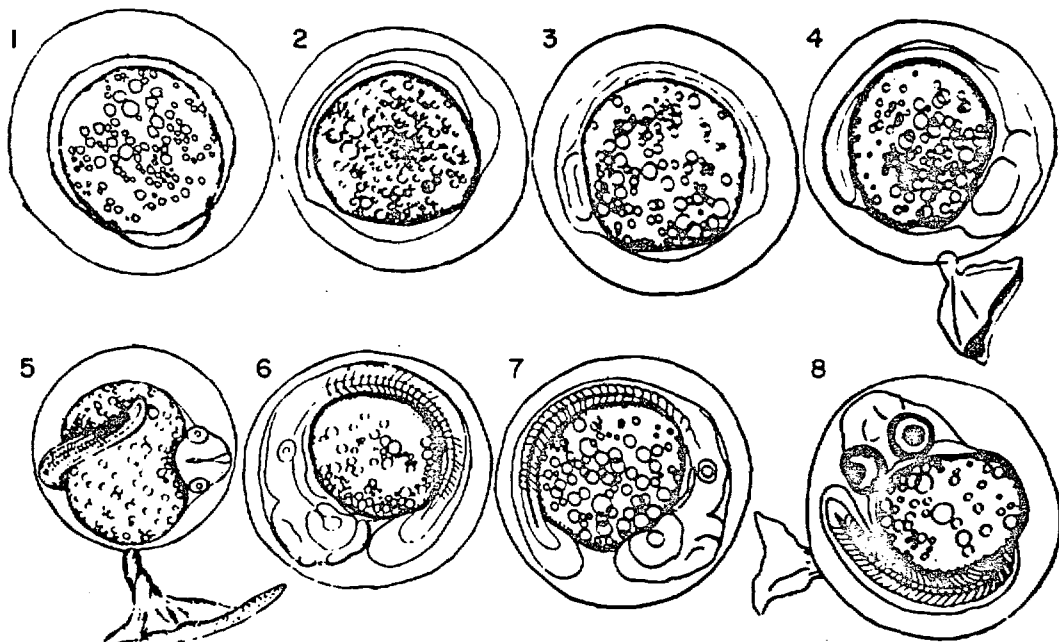
Figure 111.11.3.--Late stages of development of eggs of
the White Sea rainbow smelt (to hatching). (Taken by
Belyanina 1969 from Unanyan and Soin 1963).

and rarely exceed 102 mm (4 inches) in length, while anadromous fish may reach 356 mm (14 inches) (Scott and Grossman 1973). The average length of Osmerus mordax (as determined from 65 specimens) in Bristol Bay, Alaska, however, was only 134.4 mm, with a range of 62 to 182 mm.

Table III.11.3.—Duration of period of incubation and body length at hatching in various rainbow smelt populations (from Belyanina 1969).

Locality	sum of day-degrees	Body length at hatching (mm)	Authority
Pskov Lake	80	3.8	Meshkov and Sorokin 1952
Valday Lake	110	6.2	Chumayevskaya—Svetovidova 1945″
Rybinsk Reservoir	138	4.2-4.9	Schetinina 1954
Elbe River	60-110	5.0-6.0	Lillelund 1961
Neva River	140-180	5.4-6.0	Grib 1946
White Sea	abt. 170	6.0	Unanyan and Soin 1963
Ob estuary	132	—	Amstislavsky 1959
Miramichi River	174	5.0	McKenzie 1964

Table 111.11.4.—Rate of growth in various rainbow smelt populations (from Belyanina 1969).

Locality	1	2	3	4	5	6	7	8	9	10	11	12
Freshwater												
Pskov-Lake	7.2	2.9	3.2									
Ilmen Lake	5.2	3.0	2.5									
Valday Lake	5.3	4.6	1.3									
White Lake	6.0	2.5	2.5									
Rybinsk Reservoir	5.9	2.8	.0.7									
Kurishes Haff	6.3	4.2										
Dadey Lake	7.1	3.6	1.5	,	1	.	5					
Lazmiaden Lake	8.2	1.1	2.5	1.1	2.9							
Ladoga Lake	8.0	1.5	1.2	2.9	2.2	2.5						
Onéga Lake	6.3	2.5	0.6	1.2	0.4	0.3	0.5	0.5				
Michigan	9.2	6.5	1.4									
Upper Lake	6.5	8.3	4.2	2.3	1.2	2.3	1.2					
Sea-migrant												
Elbe River	7.1	6.3	3.9	3.9	2.6							
Finnish Gulf	7.8	3.3	2.5	2.4	1.6							
White Sea:												
Onega Bay	4.7	5.4	4.4	4.7	4.0	4.2						
Dvina Bay	4.1	5.2	3.9	3.7	2.2.	2.4	3.1	2.8	0.7			
Kandalaksha Bay	4.7	8.2	5.9	3.8	2.4	2.0						
Chesha Bay	3.5	4.6	4.4	2.7	2.5	2.8	1.7					
Yenisey River	4.5	5.3	4.3	3.5	2.7	2.0	1.6	0.5	1.1			
Lena River										3.8	2.9	1.2	1.3
Amur River	5.5	6.0	3.5									

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Food and feeding

Young rainbow smelt feed primarily on copepods, amphipods, ostracods, clad-
ocerans, and aquatic insects and small worms while in the freshwater phase
(Berg et al.. 1949, Scott and Crossman 1973). After moving into a brackish
or saltwater environment the young eat mysids, cumaceans, amphipods, and
chironomid larvae (Berg et al. 1949). Zooplankton continue to constitute
a large portion of the diet of adult rainbow smelt, but squid and young
fish are also consumed (McAllister 1963). Anadromous smelt eat juvenile
cod, various freshwater and saltwater fishes, salmon eggs, and even the
young of their own species (Berg et al. 1949, Rass et al. 1955). Landlocked
smelt are said to consume cottids, small burbot, white bass and emerald
shiner (Scott and Crossman 1973).. Although Osmerus mordax is a selective
feeder, it is also an opportunist and has been reported to consume miscel-
laneous refuse near fish processing plants in the Anadyr River estuary in
the U.S.S.R. (Rass et al. 1955, Belyanina 1969).

According to Amstislavsky and Brussynina as reported by Belyanina (1969),
rainbow smelt in the Ob River estuary feed throughout the day and night,
but peak feeding times are at 13 and 21 hours, corresponding to the vertical
migration of zooplankton. Unlike some anadromous fish, rainbow smelt do
not cease feeding during migration and spawning periods (Berg et al. 1949).

Predators and Competitors

Smelt forms an important part in the food chain in both freshwater and salt-
water environments, as it is preyed upon by a variety of organisms throughout
its life cycle. The eggs of rainbow smelt are consumed by aquatic insects
and a number of fishes including sticklebacks and adult rainbow smelt
(Belyanina 1969). Lake trout, salmon, freshwater burbot, pike, and perch
feed on smelt when they are in rivers and lakes (Berg et al. 1949, Scott
and Grossman 1973); sea mammals, birds, and fishes (especially cod) feed
on the migrant smelt schools in the ocean (North Pacific Fur Seal Commis-
sion 1962, Belyanina 1969). Nelson (1887) observed puffins bringing 4 to
5 inch smelt to their young near Stewart Island in Norton Sound, Bering
Sea. The beluga whale, Delphinapterus leucas, is also known to feed on rainbow
smelt (Dorofeev and Klumov 1936, cited by Kleinenberg et al. 1964). Even
after death the smelt continues to provide forage, because smelt carcasses
from post-spawning mortalities are scavenged by gulls, crows, and other
birds (Scott and Grossman 1973).

In the northern waters of Siberia, coregonid shrimp and Acerina cernua compete
with Osmerus mordax for chironomid larvae and various bottom dwelling micro-
crustaceans (Belyanina 1969). Young herring, capelin, whitefish and others
also compete with rainbow smelt for zooplankton, mysids, amphipods, and
cumaceans during the spring and fall in the White Sea (Berg et al. 1949,
Belyanina 1969) and presumably in other areas where their ranges overlap.

Parasites and Diseases

Rainbow smelt seem to be particularly susceptible to a wide variety of para-
sites and diseases. Smelt eggs can be infected by the parasite <u>Saprolegnia</u>
(Belyanina 1969). A microsporidian parasite, <u>Glugea hertwigi,</u> has been found
to infect smelt populations in Europe and parts of North America (Scott
and Crossman 1973). In addition, trematodes , cestodes, nematodes, acanthoce-
phalans, leeches, and the crustacean, <u>Argulus alosae,</u> have all been found
to parasitize North American smelt (Scott and Crossman 1973). A list of
thirty known parasites of U.S.S.R. smelt compiled by Bykhovsky (1962) is
given by Belyanina (1969).

In the years 1942 to 1946, large numbers of rainbow smelt in Lake Huron
and Lake Superior succumbed to some communicable disease, possibly a virus.
The total loss amounted to approximately 50 million pounds, making it one
of the greatest natural mortalities ever recorded for a North American animal
(Scott and Crossman 1973). Presumably this could happen again, possibly
in other areas.

Behavior

Turner (1886) described the formation of schools of rainbow smelt in their
approach to the spawning grounds. Apparently <u>Osmerus mordax</u> forms schools
throughout its life, from young fry to adult. Only the very largest and
oldest (6 to 8 year-old) rainbow smelt were found to swim and forage alone
(Belyanina 1969).

Anadromous smelt migrate to spawning areas in rivers or shallow coastal
waters about once a year, generally in the spring. River spawners generally
do not ascend further than 15 to 20 km from the mouth, but in the Suifun
River in the U.S.S.R. , they have been known to spawn 135 km upstream from
the sea (Berg et al. 1949, Rass et al. 1955). In the Yenisei River in the
U.S.S.R., rainbow smelt migrate over 1,000 km to Camp Goroshikha, part of
the way under ice (Berg 1948). Following spawning, the spent fish descend
the river and migrate to deeper water to escape the warm water temperatures
of summer (Belyanina 1969). Newly hatched larvae are rapidly carried down-
stream where they spend most of their early life in the less saline waters
near the coast (Berg et al. 1949).

POPULATION STRUCTURE AND DYNAMICS

Belyanina (1969) cited Kirpichnikov (1935) as feeling that males dominate
in most smelt populations. This may be true, but older age groups are composed
almost entirely of females, possibly because of a high post-spawning mortality
of males (see Table 111.11.5). The sex ratio fluctuations of a spawning
concentration were discussed in a previous section.

Table 111.11.5 .--Sex ratio (%) in different age-groups of White Sea rainbow smelt (from **Belyanina** 1969).

Year and season of sampling	Sex	Age groups						Number of fishes
		2	3	4	5	6	7-8	
1961								
Spawning	Females	—	41.5	37.0	100	100	100	**184**
concentrations	Males	—	58.5	63,0	--	--	--	270
(spring)								
Feeding	Females	52.1	54.5	75.0	75.0	100	100	234
concentrations	Males	47.9	45.5	25.0	25.0	--	--	192
(summer)								
1962								
Spawning	Females	--	66.0	50.0	72.7	66.7	100	335
concentrations	Males	--	34.0	50.0	27.3	33.3	--	282
(spring)								
Feeding	Females	52.1	56.7	70.5	100	--	--	152
concentrations	Males	47.9	43.3	29.5	—	--	--	127
(s u m m e r)								

Except for the Bristol Bay studies mentioned earlier, in which 65 rainbow smelt specimens ranged in length from 62 to 182 mm with an average of 134.4 mm, the size composition of Osmerus mordax stocks in the Bering Sea and the Gulf of Alaska has been virtually unstudied (Baxter 1975). Similarly the age composition of the spawning stocks has been investigated for U.S.S.R. and eastern U.S. rivers (Table 111.11.6), but not for Alaskan waters.

Table 111.11.6 .--Age composition (%) of spawning stocks in various rainbow, smelt populations (from **Belyanina** 1969).

Locality	Age groups															Authority
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
Pskovsko-Chudskoye Lake	90	10														Meshkov & Sorokin 1952
Rybinsk Reservoir	17	77	6													Schetinina 1954
Dadey Lake	7	41	78	1												Willer 1926
Lazmiaden Lake	6	37	38	15	4 "											Willer 1926
Ladoga Lake	6	24	32	25	11		2									Arkhiptseva 1956 and others
Onega Lake		4	28	40	20	7	1									Alexandrova 1963
Miramichi River		66	30	4												McKenzie 1964
Huron Lake		54	38	8												Baldwin 1948
Upper Lake		3	24	9	17	11										Bayley 1964
Neva River		1	28	42	24	3	1		1							Kozhevnikov 1949
White Sea:																
Onega Bay		7	32	41	17	3										Balagurova 1957
Kandalaksha Bay			30	46	23	1										Original data
Yenisey River				8	20	43	23	6								Kravchuk 1958
Lena River					6	14	83	9	28		5					Pirozhnikov 1950
Chatanga River						3	10	10	19	28	25	4	1			Lukyanchikov 1964
Anadyr River			17	21	33	13	7	4	3	1	1					Agapov 1941

Few statistics on recruitment and mortality are available for the target areas, but some factors affecting recruitment are known. One of the critical periods during early development is toward the end of the incubation when the eggs are particularly susceptible to drying, overwarming, and increased predation due to low water levels on the spawning grounds (Belyanina 1969).

Consequently, recruitment is generally higher during cold years when the water level is higher. Water temperature and food supply is also very important during the first four weeks after the larvae hatch according to Belyanina, and predation continues to take its toll throughout the life cycle. As previously mentioned, the postspawning period is often marked by mass mortality in some populations, while in other stocks smelt live to spawn three or four times (Berg 1948, Belyanina 1969).

FISHING

According to Turner (1886) and Gilbert (1895) , rainbow smelt was an important item in the diet of natives in the Norton Sound and Bristol Bay areas. The fish were caught in small shore seines and drawn up on the banks where they were piled in great heaps, then the women cleaned them and strung them up to sun dry on strings of twisted grass (Turner 1886). On the Canadian Atlantic coast, rainbow smelt have been commercially important for over 100 years (Scott and Crossman 1973). According to Berg (1948), Osmerusmordax is fished commercially on the Yenisei River and in other river systems in the U.S.S.R. For many years, however, the potential value of rainbow smelt in Alaskan waters has been largely ignored.

Like other smelt fisheries, the exploitation of rainbow smelt is seasonal, being restricted generally to the spring migration and spawning period. At this time, the smelt may be caught by seine, trap net, fyke net, and handline (Berg et al. 1949).

POTENTIAL CONTRIBUTION TO DOMESTIC AND INTERNATIONAL ECONOMY:

SUGGESTIONS FOR FUTURE RESEARCH:

   See discussions in section on smelt

LONGFIN SMELT (Spirinchus thaleichthys)
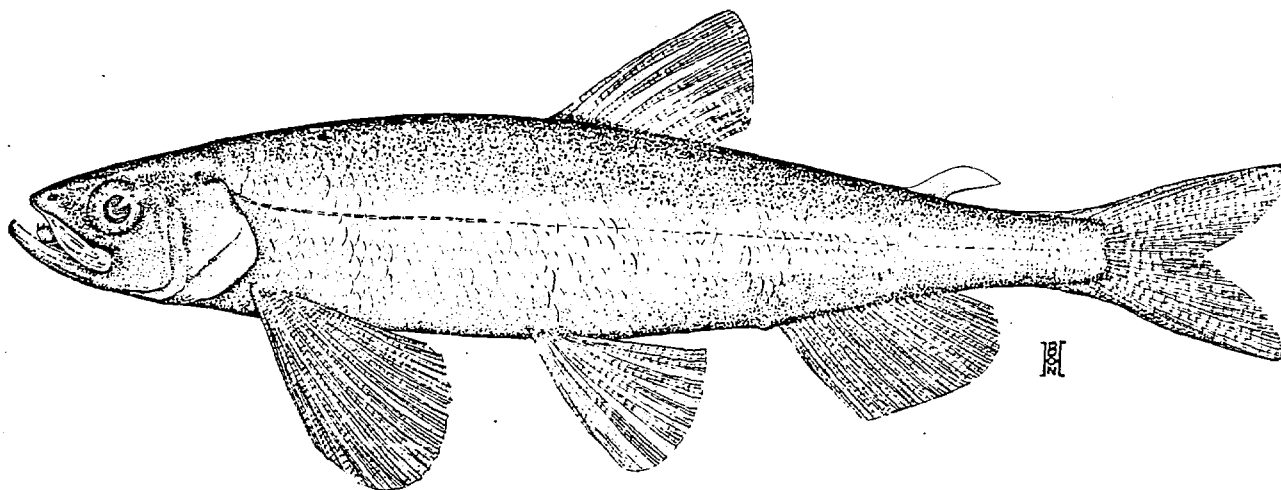
Figure 111.12.1.--Longfin smelt, Spirinchus thaleichthys
(from Hart 1973)

IDENTIFICATION

It was not until 1934 that Schultz and Chapman described the longfin smelt
from Puget Sound, and for the first time it was generally recognized as a
separate species (Hart and McHugh 1944). Later, it was found to be the same
species as a specimen named by Ayres in the San Francisco region in 1860
and, after some taxonomic study, the three scientific names below were found
to be synonymous, according to McAllister (1963):

Osmerus thaleichthys
Spirinchus dilatus
Spirinchus thaleichthys

Also regionally known as the Sacramento smelt (McAllister 1963), the longfin
smelt is frequently confused with both its close relative the night smelt,
Spirinchus starksi. and the eulachon, Thaleichthys pacificus. Since few people
recognize the differences between the minor smelt species and it is reportedly
not very numerous, very little about the distribution, biology, and abundance
of the longfin is known (Hart and McHugh 1944).

The longfin smelt can be distinguished from other similar smelts by its long
pectoral and pelvic fins and the absence of striations on the gill cover
.(Carl, Clemens, and Lindsey 1967). Its body is elongate and compressed; its
head is somewhat pointed and has a protruding lower jaw (Hart 1973). The
dorsal surfaces are olive brown and the sides and ventral surfaces are silvery
white (McAllister 1973). Spawning males are darker on the sides than females
and have profuse stippling along the back and around the scale margins (Hart
1973). In addition, some of the fin rays are enlarged and stiffened, fine
tubercles pepper the sides and paired fins, and there is a swelling of the
body in the lateral line region (McAllister 1973).

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DISTRIBUTION

McAllister (1973) and Hart (1973) give the range of the longfin smelt as occurring from San Francisco Bay, California, to Prince William Sound in Alaska, but Carl et al. (1967) report it as extending into Bristol Bay. Land-locked populations are present in Harrison Lake, British Columbia, and in Lake Union and Lake Washington in Seattle, Washington (Hart 1973). Hart noted that in the Pacific Ocean, adults are captured in shrimp trawls at depths as great as 75 fathoms (137 meters), usually in winter,

LIFE HISTORY

Longfin smelt reportedly spawn at the end of their second year between October and December (Hart and McHugh 1944, Carl et al. 1967). Although actual spawning has not been observed, the spawning of the anadromous fish is thought to take place in rivers fairly near the sea (Hart and McHugh 1944, Hart 1973). The ratio of males to females in the Lake Washington population is approximately 1 to 1 according to Hart. Each female produces about 18,100 eggs which are adjesive and have a diameter around 1.2 mm. Most fish die following their first spawning, but Hart noted that some females may survive to spawn the following year.

Literature on incubation and growth was reviewed by Hart (1"973). After an incubation period of about 40 days at $7°C$, the eggs hatch into larvae 7 mm long. Growth rate varies considerably depending on location and environmental conditions. In Harrison Lake, longfin smelt are about 42 mm long after one year and average 51 mm (males) and 54 mm (females) after two years. In Lake Washington, one year fish are about 75 mm long and two-year fish 120 mm. Marine specimens may reach a length of 152 mm (6 in.).

Young fish feed almost entirely on the shrimp-like Neomysis meredis, small adults consume copepods and some cumaceans, and larger adults eat euphausiids (Hart and McHugh 1944). The diet of the landlocked Lake Washington smelt consists of small pelagic and benthic crustaceans and insect larvae (Hart 1973).

The length of time the young spend in fresh water following hatching may be variable. Hart and McHugh (1944), basing their speculations on four specimens 61 to 72 mm in length that were found in the Fraser River, decided that the young spend a relatively long period in freshwater before migrating to the sea. However, since that time, larval longfin 22 and 23 mm in length were found in the Strait of Georgia, indicating a much shorter stay in freshwater (Hart 1973).

FISHING

Although Hart and McHugh (1944) reported that the longfin smelt was of no economic importance in British Columbia, small quantities are caught and marketed as it is said to have a good flavor (Carl et al. 1967). Because longfin smelt are grouped with eulachon in landing statistics, catch data are not available.

EULACHON (Thaleichthys pacificus)
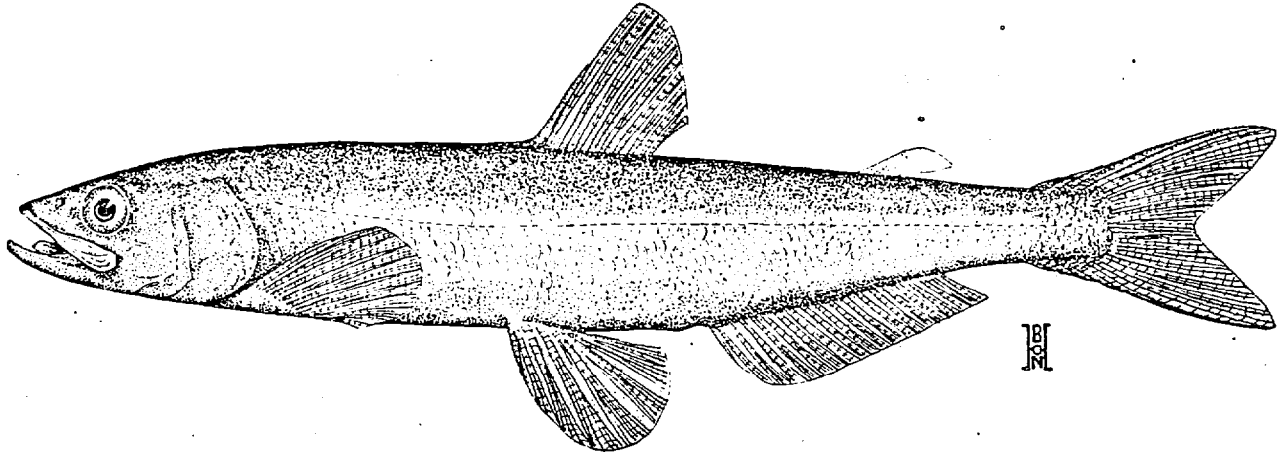
Figure 111.13.1.—Eulachon, Thaleichthys pacificus
(from Scott and Grossman 1973).

IDENTIFICATION

Although the name Thaleichthys pacificus is now generally accepted, a variety
of scientific names have been applied to the eulachon (from Scott and Grossman
1973) :

> Salmo (Mallotus) pacificus
> Thaleichthys stevensi
> Osmerus pacificus
> Osmerus albatrossis
> Thaleichthys   pacificus
> Lestidium (Bathysudis) parri

As with other smelts, marine specimens caught as incidental to other fish
are often not bothered with, and they are frequently misidentified if they
are recorded. According' to Hart (1973), at one time the prominently-toothed
marine stage of the eulachon was thought to be a separate species from the
spawning fish with weak dentition. In addition, the less abundant longfin
smelt is frequently called eulachon or candlefish as well, thereby confusing
the catch statistics.

The common name eulachon is the generally accepted spelling of the Chinook
name for the fish. Other attempted spellings which are sometimes used today
include oolakon, hooligan, ulichan, uthlecan, yshuh, and several variations
of these (Hart and McHugh 1944). The name candlefish refers to its possible
use as a candle when dried and fitted with a wick (Cobb 1907). "Fathom fish"
refers to the custom of selling strings of dried eulachon by the fathom (Hart
and McHugh 1944). In addition, the names oilfish, smallfish, and salvation
fish have also been applied (Scott and Grossman 1973).

In appearance, the eulachon resembles the rainbow smelt, having an elongate, laterally compressed body with the greatest depth at the dorsal fin (Scott and Crossman 1973). The dorsal parts are bluish-brown with black stippling and the ventral areas are silvery-white (McAllister 1963). It has a large, somewhat upward-directed mouth, a small eye, and conspicuous concentric striae on the operculum (Hart 1973). There are a number of sexual differences in appearance. Males develop numerous tubercles on the head, body, and some of the fin rays (McAllister 1963). The lateral muscles of the body wall are thickened, making the whole body much more rigid than that of the female, and the paired fins are longer (McHugh 1939). Females have more abdominal vertebrae than males and a somewhat more tapered body shape (Hart and McHugh 1944). During the spawning season, both males and females tend to lose their fairly well-developed canine teeth but their odor of freshly-cut cucumbers is particularly noticeable (Swan 1881b, McAllister 1963). The most remarkable feature of the eulachon, however, is their great proportion of body fat, which when rendered and allowed to cool assumes the color and consistency " of soft lard (Swan 1881b).

DISTRIBUTION

General Distribution

According to Hart (1973), the distribution of the eulachon ranges from the Russian River (lat 38.20°N) in northern California to the eastern Bering Sea (see map of distribution, Fig. 111.13.2). Unlike the rainbow smelt, it is found
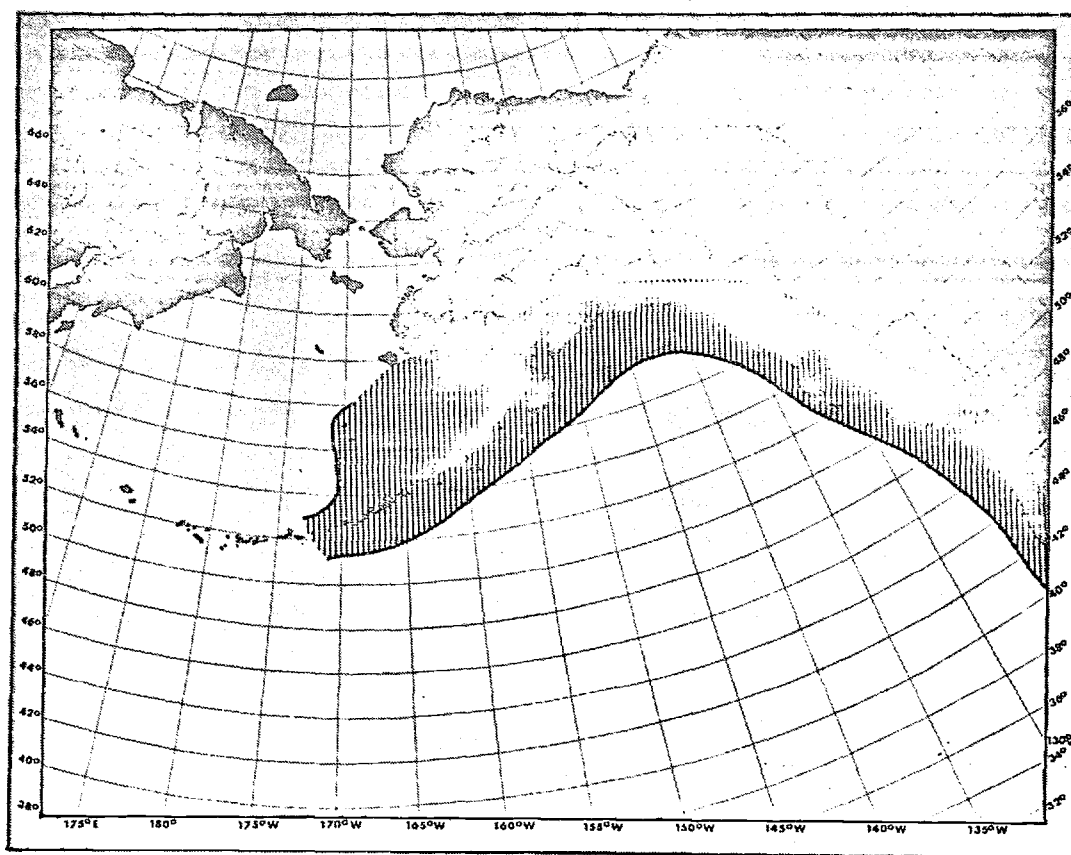
Figure 111.13.2 .--Distribution of eulachon (mapped from information given in Gilbert 1895; Marsh and Cobb 1908; Carl, Clemens. and Lindsey 1967; Hart 1973; Scott and Crossman 1973).

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only in waters adjacent to the Pacific Coast of North America, not the Asian
continent. The Columbia River, between the states of Oregon and Washington,
is the location of the largest commercial fishery of eulachon (Browning 1974).
Locations of other large spawning runs are the Fraser and Nass Rivers and
most of the other large rivers of British Columbia (Cobb 1907, Hart and McHugh
1944). The existence of eulachon spawning runs in Barkley Sound of Vancouver
Island is at present unconfirmed (Hart and McHugh 1944), but they do take
place in streams near Grays Harbor and Puget Sound (Swan 1881b).

    Specific Distribution in the Gulf of Alaska and the Eastern Bering Sea

Cobb (1907) reported that the eulachon makes only occasional and very brief .
runs in the major rivers of southeast Alaska and.Cook Inlet, "being not as.
abundant in Alaska as in British Columbia. While the runs may not be as large
as in the Nass River, B.C., Marsh and Cobb (1908) mentioned that large schools
frequented the Unuk, Stikine and Chilkat Rivers, Dyea Bay, Berners Bay and
Excursion Inlet of southeast Alaska and the important rivers of Cook Inlet
in Central Alaska. Bean (1887) stated that eulachon inhabited the shores
of the whole Gulf of Alaska and he insinuated that they were especially
abundant at the Katmai region of the Alaska Peninsula. A large run of candle-
fish was also said to occur at Three Star Point on the Alaska Peninsula
opposite Unga Island (Marsh arid Cobb 1908).

McPhail and Lindsey (1970) felt that Thaleichthys pacificus has restricted
occurrence north of the Alaskan Peninsula. Eulachon, however, are reported
from Ugashik River (Marsh and Cobb 1908) and the Nushagak River (Gilbert
1895) in the Bristol Bay region and from the Pribilof Islands (Carl, Clemens,
and Lindsey 1967). In addition, specimens which were first identified as
eulachon but whose identity now is in question (Fiscus, Baines, and Wilke
1964), were found in the stomachs of fur seals caught in Unimak Pass, Akutan
Pass, and approximately 200 km south of the Pribilof Islands (see Fig.
111.13.3).

Eulachon eggs, like those of the rainbow smelt, are adhesive and demersal
and are thus confined to the spawning grounds which are generally some
distance up a stream (McHugh 1940). McHugh found the greatest concentration
of eulachon eggs in the Fraser River at a depth of 25 feet (7.62 m) approxi-
mately 44 miles from the mouth. The larvae, being weak swimmers, however,
are very quickly swept downstream and out to sea. Tows made in the Fraser
River in the spring-summer of 1940 collected only newly-hatched larvae (McHugh
1940), but later work by Barraclough (1964) with midwater trawls in offshore
areas resulted in the capture of larvae in various stages of growth. Barraclough
found under-yearling eulachon at a wide range of depths from 15 to 105 fathoms
(27.4 to 192.0 m). Larvae, juveniles, and adults all seem to spend the majority
of their time in the food-rich echo-scattering layer of the coastal waters
(Barraclough 1964, McPhail and Lindsey 1970, Hart 1973). According to Hart
and McHugh (1944), occasional full-grown specimens are captured in trawls
or seines or are found in the stomachs of salmon taken far from the spawning
streams of the eulachon, but otherwise very little is known about the marine
Life history.

AREA	OCCURRENCE
⊛ B AT HYMASTERIDAE ⊛	
WESTERN ALASKA	
UNIMAK PASS	1
BERING SEA	
TOTAL	1
● THALEICHTHYS PACIFICUS ●	
WESTERN ALASKA	
UNIMAK PASS	1
BERING SEA	12
TOTAL	13

AREA	OCCURRENCE
△ ONCORHYNCHUS SP A	
WESTERN ALASKA	9
UNIMAK PASS	1
BERING SEA	8
TOTAL	18
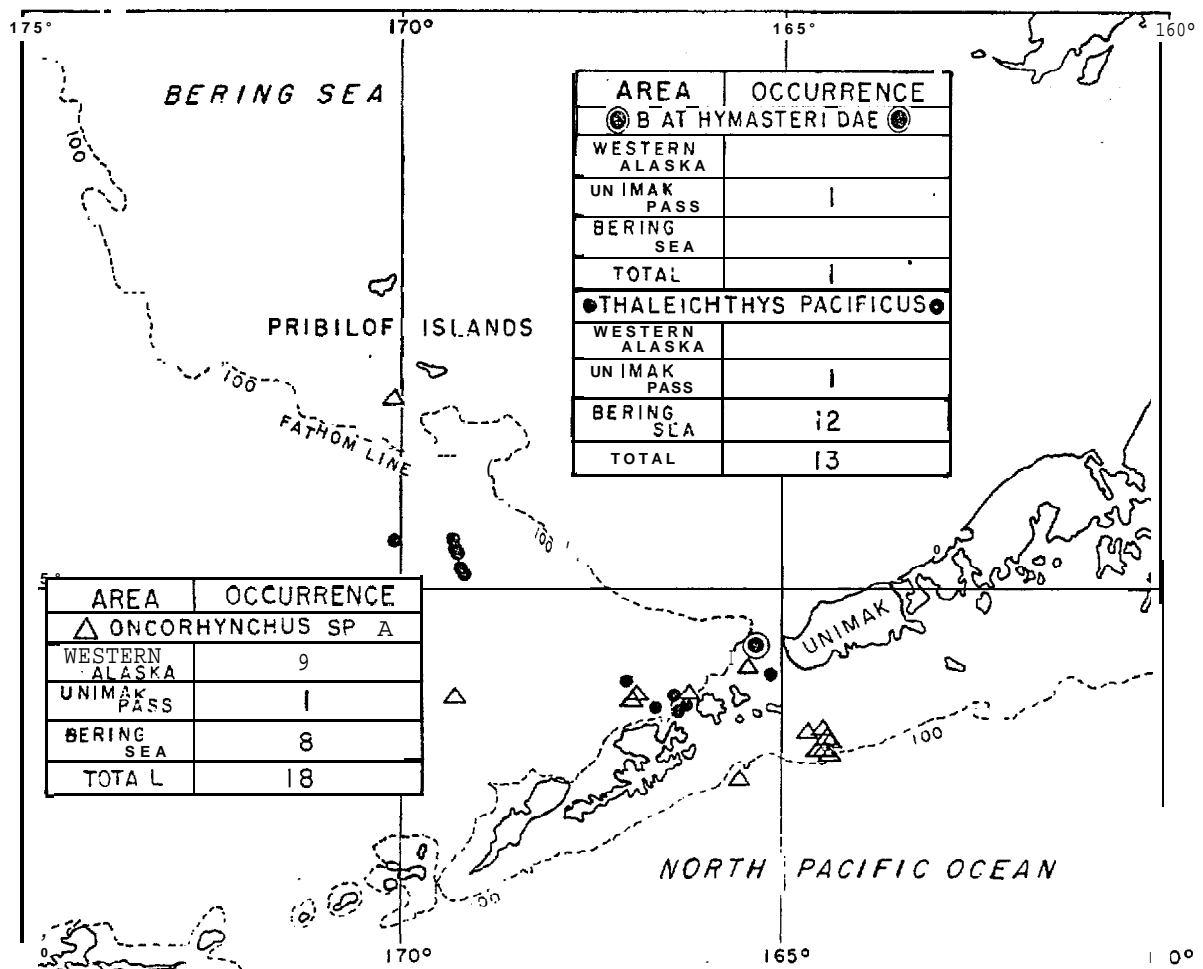
Figure 111.13.3 .--Plain circles indicate the locations where fur seal
stomachs collected in western Alaska contained eulachon (Thaleichthys.
pacificus) . (From Fiscus, Baines, and Wilke 1964.)

LIFE HISTORY

Reproduction

For many years it was thought (on the basis of otolith and scale analysis)
that the majority of eulachon spawn at the end of their second year (McHugh
1939; Hart and McHugh 1944). More recent evidence, based on the condition
of the gonads, indicates that eulachon do not spawn until the end of the
third year (Barraclough 1964, Scott and Grossman 1973). Apparently the first
sign of maturing gonads was found in late summer and winter among fish that

were over two years old (Barraclough 1964). Using Barraclough's length-frequency data and his" estimate for the youngest spawning eulachon, Scott and Crossman (1973) estimated that the first year spawners would be between 4.1 and 5.7 inches (104-114 mm) in fork length. Hart and McHugh (1944) give the standard length range of the spawning males as 5.5 to 7.4 inches (140-189 mm) and that of females as 5.5 and 7.7 inches (140-195 mm), but these figures include older spawning fish. While most eulachon die soon after spawning in their third year, some apparently live as long as five years and thus spawn several times in their lifetime (Scott and Crossman 1973).

McHugh (1939) noted that the apparent sex ratio among spawning fish changes during the spawning season. At the beginning, the number of males greatly outnumbers the female spawners, but the ratio declines as the season progresses until females may predominate toward the end (McHugh 1939, Hart and McHugh 1944). This shift in sex ratio may be due to a greater initial mortality among the males because the majority of dead eulachon cast upon the shore were observed. to be males (McHugh 1939).

As with most fish, fecundity in eulachon is related to the size of the female. Hart and McHugh (1944) found that a female of 5.7 inches (145 mm) standard length produces about 17,450 eggs while one of 7.3 inches (185 mm) produces approximately 39,600 eggs, although there is a fair amount of variation in fecundity among fish of the same size. Eulachon apparently spawn only one batch of eggs in a season.

As early as 1881, the spawning grounds of the eulachon in the Nass River were known to be 15 to 20 miles upstream from the mouth. apparently the greatest distance to which the flood tides reach (Swan 1881b). The muddy quality of the Fraser River water, however, obscured the location of the spawning grounds on that river until McHugh's (1940) investigations which discovered the presence of eggs along shoals 40 to 48 miles upstream from the sea. McHugh suggested that this area was selected because of the presence of the right-sized sand and gravel upon which to deposit the eggs; further downstream the bottom material is of finer grain.

The time and duration of the eulachon spawning season varies with locality, and the duration of the runs decreases from the south to the north of the eulachon's range (Hart and McHugh 1944). According to Browning (1974}, the spawning run in the Columbia River occurs in late winter to early spring. In British Columbia it lasts from mid-March to mid-May (Hart and McHugh 1944). In the Nass River in northern British Columbia, the fish usually come up the rivers around the middle of March just as the ice is breaking up and the water temperature is 4.4 to 7.8°C, but in exceptional years the fish will come in under the ice or the ice will have disappeared long before (Swan 1881b, Scott and Crossman 1973). Swan (1881b) also mentions that sometimes there is a second spawning run in the Nass River toward the end of June. In southeast Alaska the runs occur around the 15th of May, but they only last about three days (Marsh and Cobb 1908). Large spawning runs occur in May on the Alaskan Peninsula according to Marsh and Cobb.

Eulachon spawn en masse; the eggs are shed and fertilized over gravel or sand banks onto which they settle and adhere (Browning 1974). No nest is built; the eggs are simply abandoned (Scott and Crossman 1973). Swan (1881b) noted that following spawning the eulachon disappeared as quickly as they had arrived. The majority apparently die soon after the first spawning, although spent eulachon in good condition have been caught in the Strait of Georgia and there are other indications that some eulachon live and spawn in subsequent years (Barraclough 1964).

Eulachon eggs are somewhat irregular in shape with many oil globules in the yolk (Hart and McHugh 1944). Although the eggs vary considerably in size, the average range is from 8 to 10 mm in diameter (Hart and McHugh 1944; Scott and Crossman 1973). McHugh (1940) described the way in which the egg is attached to the sand grain substrate as being similar to that of the rainbow smelt (see Fig. 111.13.4). An outer adhesive membrane breaks and inverts, remaining attached to the egg at one point, and forms a sticky pedicel which adheres to the sand grains, providing an anchor.
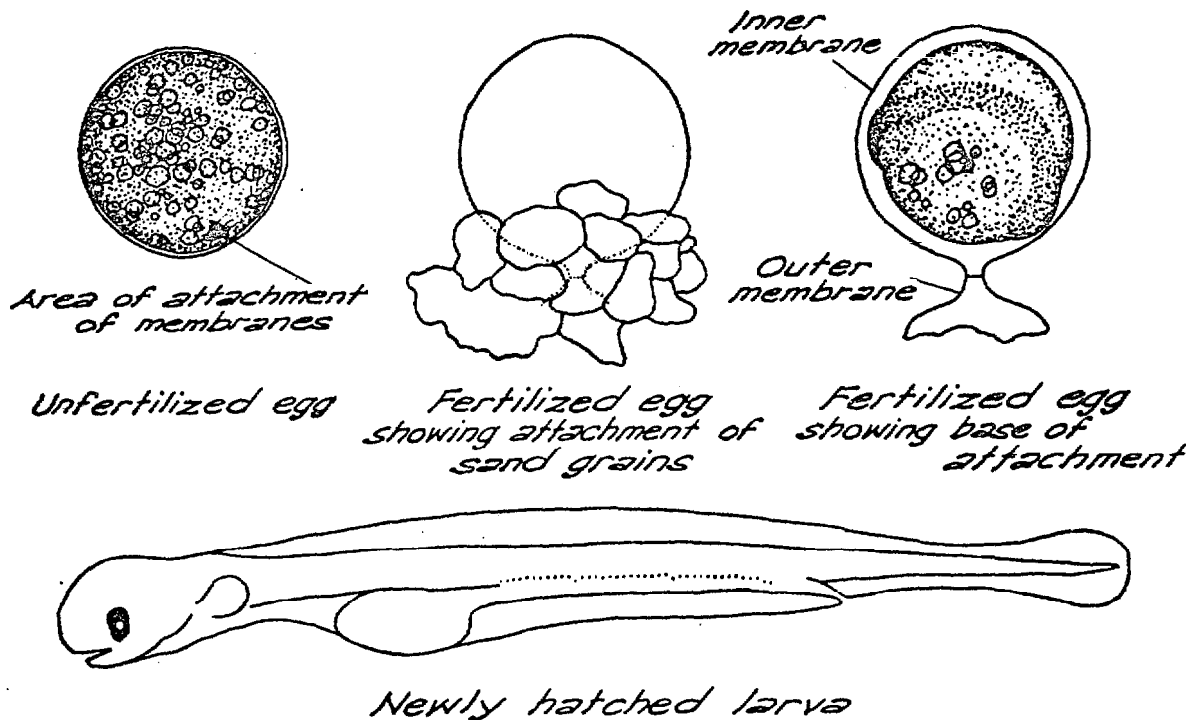
Figure 111.13.4.—Eulachon eggs showing the form of attachment to the substrate, and the newly hatched larva (from McHugh 1940).

Growth

After 30 to 40 days incubation at a water temperature of 4.4 to 7.2°C, the eggs hatch and a larva 5 to 7 mm in length emerges (Hart 1973). The slender, trans- parent larva (Fig. 111.13.4) of <u>Thaleichthys pacificus</u> is similar in appearance to that of the Pacific herring, but the yolk sac is attached further back and the anus is further forward (McHugh 1940). As the larvae are relatively weak swimmers, the river current soon carries them out to sea (Hart and McHugh 1944). Larval growth is rapid under most circumstances as shown by the fact that some larvae collected in the salt water in April were already 23 mm in length (Scott and Crossman 1973). A description of larval development is given by Barraclough (1964), along with a drawing of a 34 mm larva (Fig. III.13.5).
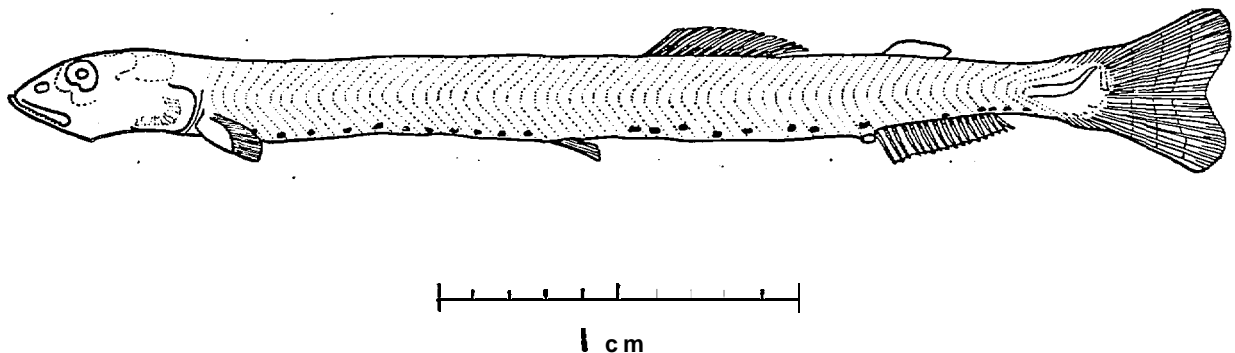
Figure 111.13.5 .--Larval eulachon 34 mm in "length (from Barraclough 1964).

Growth rates are quite variable because some larvae may be caught in eddies where suitable forage is limited and growth may be curtailed (Hart 1973). In general, however, most young in British Columbian waters are 46 to 51 mm (1.8 to 2.0 inches) in length (Scott and Crossman 1973) by the December following hatching, and by the end of the first year they are 61 mm long (Hart 1973). The length at the end of succeeding years of growth is given in Fig. 111.13.6. Although 305 mm (12 in.) is frequently given as the maximum size (Hart and McHugh 1944, McAllister 1963), Scott and Grossman (1973) feel that all reported lengths in excess of 229 mm (9 in.) should be considered doubtful. The average length of a Fraser River eulachon is between six and seven inches (152-178 mm) standard length, and Hart and McHugh (1944) did not find any much over eight inches (203 mm). Measurements of spawning eulachon in the Fraser River indicated very little difference in size between males and females, thus there may be no sexual difference in growth rates (McHugh 1939).
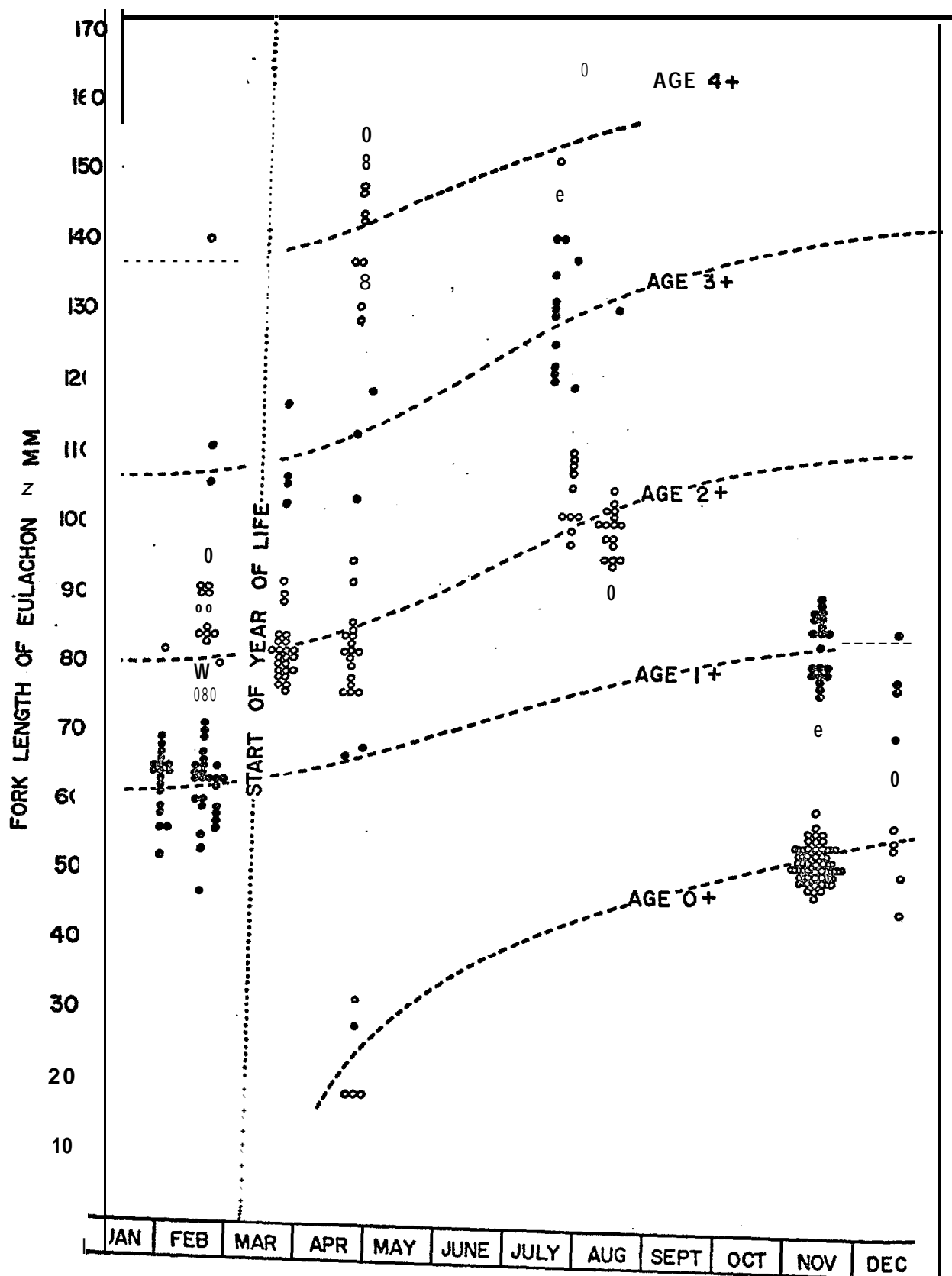
Figure III. 13.6.--Length-frequency distributions of samples of eulachon, Thaleichthys pacificus, taken from various locations of the British Columbia coast during different seasons (from Barraclough 1964).

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Food and **feeding**

Newly emerged larval **eulachon** probably do not feed during their transport
to salt water, but live off the yolk (Scott and **Crossman** 1973). Once they
reach the marine environment, **however,** they begin consuming the abundant
plankton found in the echo-scattering layers. The smallest feeding **eulachon**
found was observed to be eating ·copepod **larvae** (Hart 1973). **Phytoplankton,**
copepod eggs, **copepods, mysids, ostracods,** barnacle **larvae, cladocera, worm**
larvae, and even larval **eulachon** were found to be the food of larvae and
postlarvae 25 to 51 mm (1 to 2 in.) in length (Hart 1973). The diet of
juvenile and adult **eulachon** consists almost exclusively of **euphausiids,**
with **copepods** and cumaceans consumed occasionally (Hart and McHugh 1944,
McAllister 1963, **Barraclough** 1964, Hart 1973).

Predators and Competitors

According to Hart and McHugh (1944), the **eulachon** or **candlefish** is a very
important intermediate step in the food chain between the zooplankton and
the larger fish, marine mammals, and birds. Small salmon, **lingcod,** and other
fish feed on the young larvae and postlarvae near the **river mouths** (Hart
1973). Salmon and fur seals consume adult **eulachon** at some distance from
the spawning streams (Hart and McHugh 1944). Hake are also known to eat
eulachon (Outram and **Haegele** 1972). **Eulachon** comprised nearly 82% of the
diet of fur seals in the Gulf of Alaska during-June 1952 **(Wilke** and Kenyon
1954), and **eulachon** were found in the stomachs of 12 out of 13 seals collected
in the Bering Sea between July 21 and October 10 **(Fiscus** et al. **1964).** Fur
seals may consume large quantities of **eulachon** only seasonally, for at other
times of the year **eulachon** have been found to compose only 0% to 6.7% of
the stomach contents by volume (North Pacific Fur Seal Commission 1962,
1971, 1975; **Fiscus** 'et al. 1964). During the spawning migration, however,
eulachon probably constitute a major part of the food of the accompanying
predators. Among the known predators at this time are halibut, cod, dogfish,
other ground sharks, seals, sea **lions,** porpoises, and finback whales (Swan
1881b, Hart and McHugh **1944). Killer whales also follow** the migrating schools
and consume some of the **eulachon** feeders (Hart 1973). As the **candlefish**
rise to the surface on entering the spawning river they are attacked from
above by flocks of gulls, ducks, and other sea fowl (Swan 1881 b). In the
rivers sturgeon eat tremendous amounts of the migrating fish **(McPhail** and
Lindsey 1970). After spawning, the dying **eulachon** provide forage for birds
and for bears and other terrestrial mammals which come long distances in
order to feed on them (Marsh and Cobb 1908).

The competitors of **eulachon** are other plankton feeding fish and **euphausiid-**
consuming mammals such as the finback whale which **also** forage in the echo-
scattering **layer** (Scott and **Crossman** 1973).

Parasites and Diseases

Arai (1969) listed parasites of **Thaleichthys pacificus** as including the
Digenean **trematode** Lecithaster gibbosus, the cestode Phyllobothrium, and
the nematode Contracaecum. No mention of **eulachon** diseases was found in
the literature.

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Like other smelt, the **eulachon** spends most of its life in schools, and during the spawning migration- these schools join to form even larger congregations which swim up **the** river together (Browning 1974).

There is some indication that the spawning **eulachon** return to the stream in which they hatched, for there is a difference in vertebral count between the Fraser River fish and the fish of the rivers further north which would be eliminated if much mixing occurred between the runs (Hart and McHugh 1944). Migrating **eulachon** remain in the deep echo-scattering layer until they approach the mouth of the spawning river, at which time they rise to near the surface (Swan 1881b). As they move up the rivers they travel fast, as much as 25 to 35 miles per day (Browning 1974). According to Scott and **Crossman** (1973), **those** fish that survive the spawning do not remain very long in freshwater, but quickly find their way back to the sea. Likewise, " the newly hatched **larvae** spend a minimum time in freshwater, for they are swept rapidly downstream, sometimes 40 miles in less than 24 hours (Hart **and** McHugh 1944).

POPULATION STRUCTURE AND DYNAMICS

Sex Ratios and Size Composition

McHugh (1939) discussed the change in sex ratio on the spawning grounds with the passage of time. but he felt that **the** apparent predominance of males most of the time was **not** a certain indication of the sex ratio of the population **as a whole.**

Figure **III.13.6** gives the length-frequency distribution of **eulachon** that were taken off the coast of British Columbia **at** different times of the year. The size composition of spawning fish in the Fraser River, **compiled by Hart** •and McHugh (1944), is illustrated in Fig. 111.13.7. Comparing the two figures and allowing for the difference in measurement , it would seem that Fraser River fish are of a greater **length** than would be expected. Additional data would be necessary to explain the disparity.
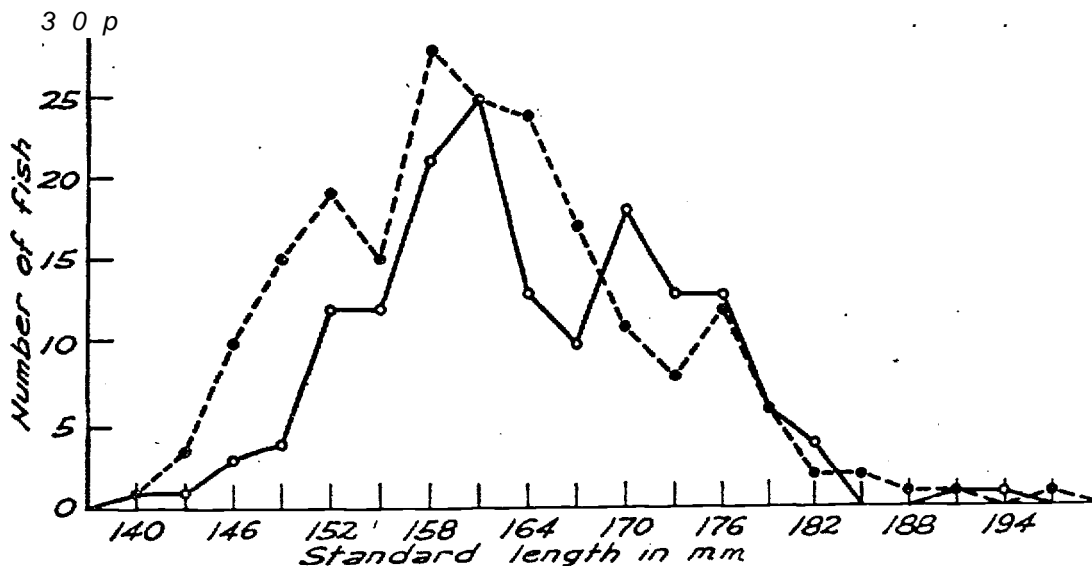
Figure 111.13.7. --Length distribution of Fraser River **eulachon** in 1941. Solid line – males, broken line – females (from Hart and McHugh 1944).

Abundance and Density

According to Cobb (1907), the eulachon is not as abundant in Alaska as in British Columbia. The eulachon spawning runs are of very short duration in the rivers of southeast Alaska and Cook Inlet (Marsh and Cobb 1908), possibly indicating that fewer numbers of -schools "participate in the migrations. As there is no commercial fishery in Alaska for eulachon, few catch statistics are" available and it is difficult to obtain an estimate of the present "population size.

Mortality

As the majority of eulachon die soon after spawning at the age of three years, the natural mortality is very high, but there is no reliable estimate. " at present of the number of eulachon which survive the first spawning to spawn again in succeeding years.

FI SHING

Many early historians on the Pacific coast of North America" have commented on the importance of the eulachon to the natives. The arrival of the first of the migrating spawners was anxiously awaited by the Indians because the eulachon came during a time of the year in which other sources of food were scarce (Swan 1881b). As the fish entered the mouth of the river, some were caught by the natives on an oar-like pole about 18 feet long, the blade of which was studded with wooden pins or pieces of sharp wire. Further upstream near the sand bars where the eulachon spawned, purse-like nets were set into the sandy bottom to act as a trap for the fish during ebb tide when the force of the current drew them downstream (Swan 1881b). Some of the captured eulachon were eaten fresh, others were dried for winter consumption, but the majority were rendered into oil which was then used for cooking or as a condiment (Carl et al. 1967). Indians from the interior would travel long distances along the famous "grease trails" in order to trade for stores of the eulachon oil (Hart and McHugh 1944).

In 1877, a commercial fishery for eulachon developed on the Nass River, with the intention of manufacturing candlefish oil for sale on the foreign market (Hart and McHugh 1944). The Indians were so eager to buy any oil that was produced that little remained for the export trade and visions of a large foreign market faded. James Swan (1881b) reported that the Hudson's Bay Company station at Fort Simpson, British Columbia, had been salting, and smoking Fraser River eulachon which was later either sold in the Victoria market or shipped to London, England. These Canadian fisheries reached their peak of production in 1903 when 4,070 barrels were salted, 45,200 lbs. were smoked, and over 1,000,000 lbs. were sold fresh for a total value of $96,436 (Hart and McHugh 1944). Today there is a limited commercial fishery on the Fraser River; most of the eulachon caught by drift gillnets are sold as food for fur-bearing animals, but some is used for human consumption (Scott and Crossman 1973). In northern British Columbia commercial exploitation is prohibited, reserving the runs for the native fisheries only, which still take substantial numbers (Hart 1973). The largest present-day commercial fishery is on the Columbia River where six million pounds were taken in 1945, and every year since then over one million pounds have been harvested, exceeding the catch rate of every other commercial species on the river (Browning 1974).

Browning reported that most commercial and current native fishing for the eulachon is done with-a drift gillnet in the spawning rivers. For research purposes gillnets have the disadvantage of being size-selective, and for commercial purposes a drawback is that the fish tend to get battered and bruised upon removal from the mesh. Recently a shrimp separator trawl has been used in the Columbia River with some success—the trawl takes the smelt at high catch rates without damaging them appreciably and does not harm the salmon and steelhead resources. Long-handled dip nets are used by both commercial and sports fishermen on the tributary rivers.

Meaningful catch statistics on the eulachon are somewhat limited. For some time the Department of Fisheries in British Columbia kept records on the catch from the Fraser River but, as methods of recording the statistics have changed over the years and the fishing effort has fluctuated greatly, it is difficult to make valid assumptions on availability based on the statistics (McHugh 1941). In 1941 a more valid system of recording data was set up, and three years later a comparison of the accumulated statistics indicated that there was no major change in availability of eulachon during that time (Hart 1943). Eulachon catch statistics from Alaskan waters, however, are markedly incomplete and few conclusions can be drawn concerning any changes in availability.

POTENTIAL CONTRIBUTION TO DOMESTIC AND INTERNATIONAL ECONOMY

In much of its range, eulachon remains an essentially unexploited species with some potential for future fishery development. While the eulachon has been praised by many as being a great table delicacy, at present most of the commercial catch is used as food for fur-bearing animals (Hart and McHugh 1944). The importance of the eulachon as a forage fish cannot be denied, although their relative importance in the diet of both fish and mammals is difficult to determine (Barraclough 1964).

BATHYPELAGIC FISHES

In the deeper waters of the North Pacific Ocean and Bering Sea are a number of species of fish which are seldom caught and which are generally classified as **bathypelagic** fish. Included in this broad classification are **members** of the following families: Argentinidae, **Bathylagidae, Opisthoproctidae, Gonostomatidae,** Sternoptychidae, **Melanostomiatidae, Malacosteidae, Chauliodontidae, Alepocephalidae,** Searsidae, **Alepisauridae,** Anotopteridae, Scopelarchidae, **Paralepididae, Scopelosauridae,** Myctophidae, **Agonidae,** and others.

Some of these families are rather **well** defined **taxonomically.** So few specimens of some fish have been collected; how-ever, that there is confusion as **to** whether they belong to the same or different families. Even" within 'some rather well defined families where relatively large numbers have been caught, a substantial amount of confusion exists in classification at the genus and species levels. This confusion is sometimes aggravated by the fact that some features used by taxonomists are altered by differences in environmental conditions, thus fish from different areas may be classified as being different species although they are **the** same.

Generally speaking, the **bathypelagic** fish are considered as being rare, although some species are very abundant. Occasional specimens are taken by commercial fishermen fishing for **other species.** Most are caught **by** research vessels using specialized sampling gear, **typically plankton nets,** Isaacs-Kidd **trawls,** or the so-called bongo nets. Occasionally, specimens are found in the stomachs of predator fishes or animals caught by commercial or research vessels. Essentially, sampling devices are limited in design and use. Thus, a species or family considered as rare may in fact be rather common in the ocean, and the lack of knowledge may be attributed ·to the fact that no one knows how, where, or when to catch a particular fish as a mature specimen.

Some knowledge exists about the mature fish of these various families, but almost nothing is known of their life histories , maturation, reproduction, nutrition, growth , and other features. Thus the places of the various families and species in the marine ecosystem are unknown. To various degrees, their distributions appear to be limited , if not controlled, by the **environment.** Some are characteristically found at greater depths, or warmer temperatures, or higher oxygen levels than others. Some migrate vertically with changes in **light** intensity and **some** probably make seasonal migrations.

According to Parin (1961), as a whole, the ichthyofauna of the upper **bathy**pelagic layer of subarctic waters of the **North** Pacific is characterized by (a) a quantitative improverishment of species (about 40 total), (b) considerable isolation evidenced by the presence cf a number of endemic genera and species", (c) uniformity within the limits of the **North** pacific subarctic waters based on the similarity in the main features **of** hydrological conditions, and (d) the existence of differences between the fauna of the northeastern and northwestern parts of the ocean apparently as a result of differences in the oxygen regime of these regions.

Because most of the bathypelagic fishes are relatively small, their primary
importance appears to be as food for other fishes and for marine mammals.
On the basis of our review of literature, we determined that fishes of
two families, the Bathylagidae (deepsea smelts) and the Myctophidae (lantern-
fishes), as forage species, probably were the most important bathypelagic
fishes of the eastern Bering Sea and Gulf of Alaska. Even with fishes
of these two families, which may be common to abundant depending upon
place, time and method of catch, the bulk of the literature is concerned
with taxonomy and distribution. Little is known about the biology, life
history, and population structure of any species.

As a result of the paucity of information, we have not reviewed the bathy-
pelagic fishes in the same format as the other species in this report,
but the species are limited to, and discussed under, the two broad family
headings of Bathylagidae and Myctophidae. The particular species discussed
are those that have appeared most frequently in experimental catches.
The limited experimental catches by various agencies and types of gear
are detailed in figures and tables in Section IV and in the appendix to
this report.
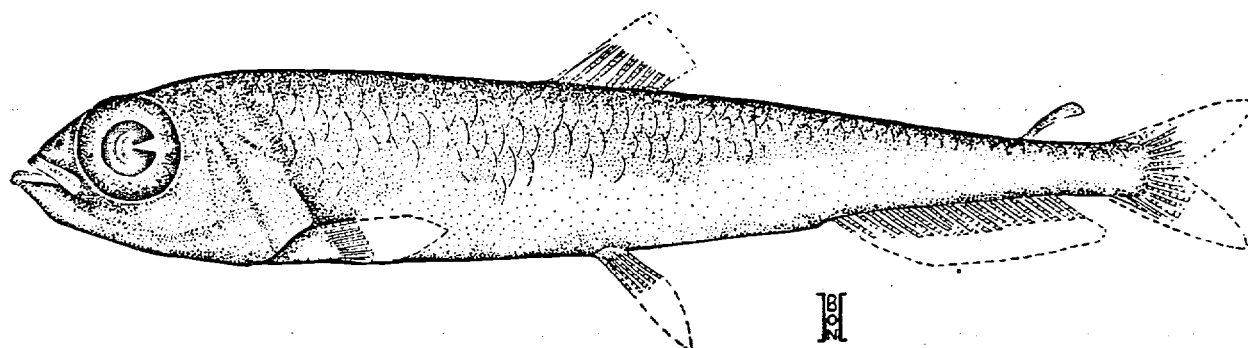
Figure X11.14.1 .—A bathylagid fish, the stout blacksmelt,
Bathylagus milleri (from Hart 1973).

Fishes of the family Bathylagidae are usually small and generally inhabit
deep water. Few enter water less than 200 m deep (Bailey et al. 1970).
According to Musienko (1970), a single species of the genus Leuroglossus
and two species of the genus Bathylagus are found in the Bering Sea, and
Fedorov (1973a) lists the following species of Bathylagidae in the Bering
Sea:

Mesopelagic ichthyocoenosis
    Bathylagus ochotensis   30-1000 m depths

Bathypelagic ichthyocoenosis
    Bathylagus milleri   60-1420 m
    Bathylagus pacificus   50-1604 m
    Leuroglossus stilbius schmidti   0-1800 m

Bathylagus fry were caught at depths more than 1000 m in the central and
western Eering Sea of lat 60°N in June (Musienko 1970).

As early as 1899, Lucas studied 373 fur seal stomachs and found that the
"seal fish" [Bathylagus] was third in importance as a food item in the
Bering Sea (Wilke and Kenyon 1954). Studies of fur seal stomachs in 1963
and 1964 indicated that Bathylagidae were fourth in importance as foods
in 1963 and comprised 7.2% of the volume of stomachs in summer (North
Pacific Fur Seal Commission 1971). The results were similar in 1964, and
squids and Bathylagidae were the main foods in September (North Pacific
Fur Seal Commission 1969).

Some of the information available on four species of **Bathylagidae** follows:

Bathylagus milleri (Stout blacksmelt)

The stout blacksmelt (see Fig. 111.14.1) occurs from southern California
through Oregon, Washington, British Columbia, Alaska, Bering Sea, and
Okhotsk Sea (Gilbert and Burke 1912). It is found at depths from the surface
at night to 1420 m (Grinols 1965, Taylor 1968). In color it is black,
and it reaches a length to 16.5 cm (Hart 1973).

Musienko (1970) notes that no information on reproduction and development
of B. milleri has been published:

Bathylagus pacificus (Slender blacksmelt)

The distribution of the slender blacksmelt is in the eastern Pacific Ocean
from northern Baja California northward through Oregon, Washington, British
Columbia, the Gulf of Alaska to the Bering Sea (Hart 1973). Fitch and
Lavenberg (1968) stated that it lives at depths greater than 306 m, Novikov
(1970) found it rarely and at depths more than 300m, but LeBrasseur (1970)
found the maximum"deFth of catches to be 150 m. So far as is known, it
does not undertake vertical diurnal migrations. Chapman (1937) reported
that specimens collected during deep sampling tows (700 m of wire out)
in the Gulf of Alaska ranged in length from 2.2 to 15.5 cm, and a full
grown adult is about 25 cm long and weighs approximately 124 grams (4 oz)
(Fitch and Lavenberg 1968).

Studies mentioned by Fitch and Lavenberg showed otoliths of an individual
15 cm long had five winter rings, and several specimens 11 cm long had
three winter rings. Spawning apparently occurs in spring, because ripe
eggs were toted in ovaries at that time. The slender blacksmelt feeds
predominantly on crustaceans and is in turn eaten by numerous larger
predators.

Bathylagus ochotensis (Eared blacksmelt)

The eared blacksmelt occurs in the northeast Pacific and the Okhotsk Sea
(Hart 1973). Northward from northern Baja California it has been found
off Oregon and Washington at 400 m (Aron 1960a, Grinols 1965). Off British
Columbia, it is distributed from near the surface to 730-825 m in water
from 860 to 2,380 m deep (Taylor 1967). and it also has been found between
the surface and 60 m (McAllister 1960).

The length has been recorded to 12 cm (Hart 1973).

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Bathylagus (Leuroglossus) stilbius schmidti (California smoothtongue)

According to Bailey et al. (1970), the genus **Leuroglossus** has been redesignated as **Bathylagus.** The California smoothtongue is found off Washington northward off Alaska, probably in the Gulf of Alaska, to the Bering and Okhotsk Seas, and possibly Kamchatka (Musienko 1970, Hart 1973). A school of 5-10 cm fish was caught at the surface in the Strait of Georgia, B.C. (Barraclough 1967), and the fish has been taken at depths to about 730 m (Grinols 1965). Musienko wrote that larvae and fry were caught in June, July, September, and January in the central and southwestern Bering Sea usually over depths exceeding 1,000 m, and some larvae were caught over depths of 125 and 134 m.

According to Musienko, no information has been published on reproduction and development of the California smoothtongue.

The food of this fish in the Strait of Georgia was euphausiids, copepods, barnacle larvae, and fish eggs (Barraclough 1967). predators that have been found to feed on larvae and juvenile smoothtongues 'include young herring, eulachons, sand lance, and chinook salmon (Hart 1973).

MYCTOPHIDAE (Lanternfishes)
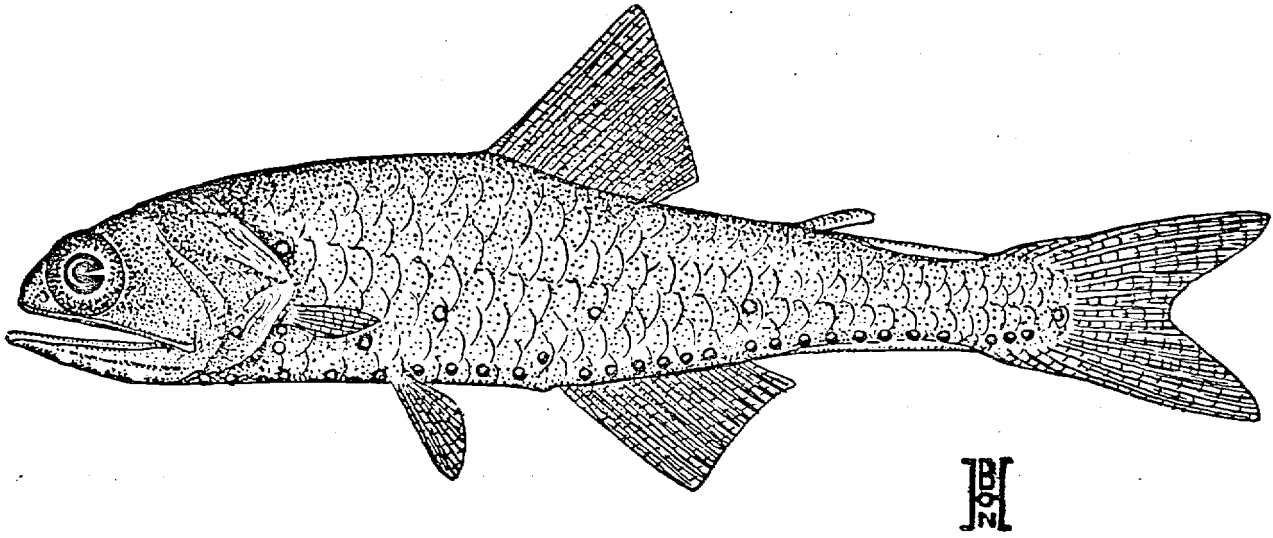
Figure 111.15.1.—A myctophid fish, the northern lampfish,
Stenobrachius leucopsarus (from Hart 1973).

During the early phases of our review of literature on the myctophids,
it became apparent that a large number of species in this family were
found in the Pacific Ocean and that they were broadly distributed. It
was also apparent that nothing was known of the biology of most of the
species and, at best, only a little was known of a few of the species.
At the same time, it became apparent that the lanternfishes must be of
significant importance in the ocean ecosystem, although their role in
the system is poorly defined. Because a complete inquiry into nearly a
hundred species was impossible, a decision was made to present the available
information in four parts. First, a general introduction about the myctophids;
second, a summary of the general distribution of the more common species
in the Pacific Ocean and Bering Sea; third, a brief synopsis of the biology
and distribution of a few species for which there is some information
in the Gulf of Alaska and Bering Sea; and, fourth, a summary of the creatures
known to feed on the myctophids.

General Introduction to the Myctophidae

The lanternfishes are relatively small fish that are generally found in
moderate depths , although some are found in deep waters. All have photo-
phores below the lateral line, and most have air bladders. The family
Myctophidae is the richest group of typical bathypelagic fish and is
especially characteristic of pelagic zones of the ocean (Rass 1960).

Clarke (1973) collected 47 species of lanternfish near Hawaii. These species
could be separated into groups which showed some similar behavior and
life history patterns that tended to apply to the myctophids in the Pacific
Ocean in general. Some of Clarke's observations are summarized below.

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Most of the lantern fishes migrate vertically, moving toward the surface at night and returning to depths during the day, although some apparently do not. As very young fish, some do not migrate vertically but start to do so as they grow larger. The young fish tend to be in shallower waters than the adults. Some, but not all , of the species migrate seasonally and nearly all show a variation in depth related to the phase of the moon. Different species of lanternfish may intermix but tend to do so only when they are about the same size. The most abundant species near Hawaii spawn principally in the spring and summer, apparently coinciding with the peak of zooplankton production. According to Fitch and Lavenberg (1968), most lanternfishes live three to five years, and they may live as long as eight years. The ages at maturity and life spans of colder water species are greater than for tropical species (Clarke 1973).

Myctophids and gonostomatids are the most abundant bathypelagic finfishes in the world oceans (Fitch and Lavenberg 1968). The abundance can vary seasonally, and on some occasions concentrations may be dense enough to create a "deep scattering layer" that is visible to hydroacoustic equipment (Taylor 1968).

The distribution of different species, or at least the most common species, is related to or controlled by the water masses in which they are found. Some are characteristically found in warmer or colder waters, high or low salinities, high or low oxygen levels or they are influenced by other variables in the environment (Parin 1961). Parin noted that waters of the western Pacific tend to have a higher oxygen content than eastern waters, and this seems to determine the distribution of some species. On one occasion off California, an abrupt drop in water temperature caused a mass mortality of the blue lanternfish, Tarletonbeania crenularis (Aughtry 1953).

The myctophids and other vertically migrating micronekton generally eat various types of zooplankton and probably account for most of the zoo-plankton consumed in the tropical open ocean, at least near Hawaii (Clarke 1973).

Some of the body proportions, or morphological characteristics of the lanternfish may be affected by the environment. Mead and Taylor (1953), for example, found differences in body proportions between samples of Tactostoma macropus caught off Japan and those from California-waters. Other authors have experienced similar problems with other species. These morphological differences induced by the environment have contributed to the present confused taxonomic status of many of the species, and the actual number of species in existence and the number misidentified is unknown.

Investigations carried out in the western Pacific Ocean in" tropical "and subtropical waters by the Russian research vessel VITYAZ identified 66 species of lanternfishes of the genus Diaphus (Kulikova 1961). Clarke (1973) reported 47 species of lanternfishes near Hawaii. Fitch and Lavenberg (1968) found more than 30 lanternfishes .

from 20 genera had been taken off California, and Taylor, Fujinaga, and Wilke (1955) reported approximately30 species from Japan. In three cruises by the Fisheries Research Board of Canada sampling with midwater trawls off the Queen Charlotte Islands, slightly more than 10,600 fish were caught, of which 81% were of the family Myctophidae (Taylor 1967),.

Very little information was found in literature about the number of myctophid species of the Bering Sea and Gulf of Alaska. In his review of ichthyofauna of the Bering Sea, Fedorov (1973a) listed three species of mesopelagic myctophids and five bathypelagic species:

	Depth
Mesopelagic ichthyocoenosis	
Diaphus theta	0-1068 m .
Hierops (Protomyctophum) thompsoni	0-1100 m
Tareletonbeania crenularis	0-1100 m
Bathypelagic ichthyocoenosis	
Lampanyctus jordani	300-1001) m
Lampanyctus regalis	0-1630 m
Lampanyctus ritteri	223-1095 m
Stenobrachius leucopsarus	0-2969 m
Stenobrachius nannochir	0-3250 m

Chapman (1940) described a number of species taken in the Gulf of Alaska, but many names have since been changed-and his findings have been superseded in many cases by those of other authors.

General Distribution of Myctophidae in the Pacific Ocean and Bering Sea

Figure III.15.2 gives an indication of where a few of the species of myctophids are distributed throughout the Pacific Ocean. The genera represented are all found in the areas of concern to this report, although some of the species are not. The patterns of distribution of the species suggest that various hydrological features influence these distributions.

Parin (1961) studied the distribution of some of the myctophids (Fig. 111.15.3) and the ocean currents (Fig. 111.15.4) in the northern latitudes of the Pacific. Allowing for seasonal or annual variations in the actual locations of the ocean currents and the location of the sampling stations, it is apparent that the distribution of some of the species is influenced by current flows in the Gulf of Alaska, particularly in the area of the Alaska Gyre. The results obtained by Bekker (1963b), shown in Figure 111.15.5, are reasonably consistent with those obtained by Parin.

Aron (1962) analyzed data on myctophids caught in the Gulf of Alaska and Bering Sea during a cruise of the research vessel Brown Bear. His report included myctophid species which are particularly abundant in the areas of concern to this report. Some of his results are summarized in Figures 111.15.6 and 111.15.7. Relationships between abundance and distribution and the ocean currents can be shown by comparing these figures with those of Parin (1961) and Bekker (1963b) (Figs. 111.15.3, 111.15.4, 111.15.5).
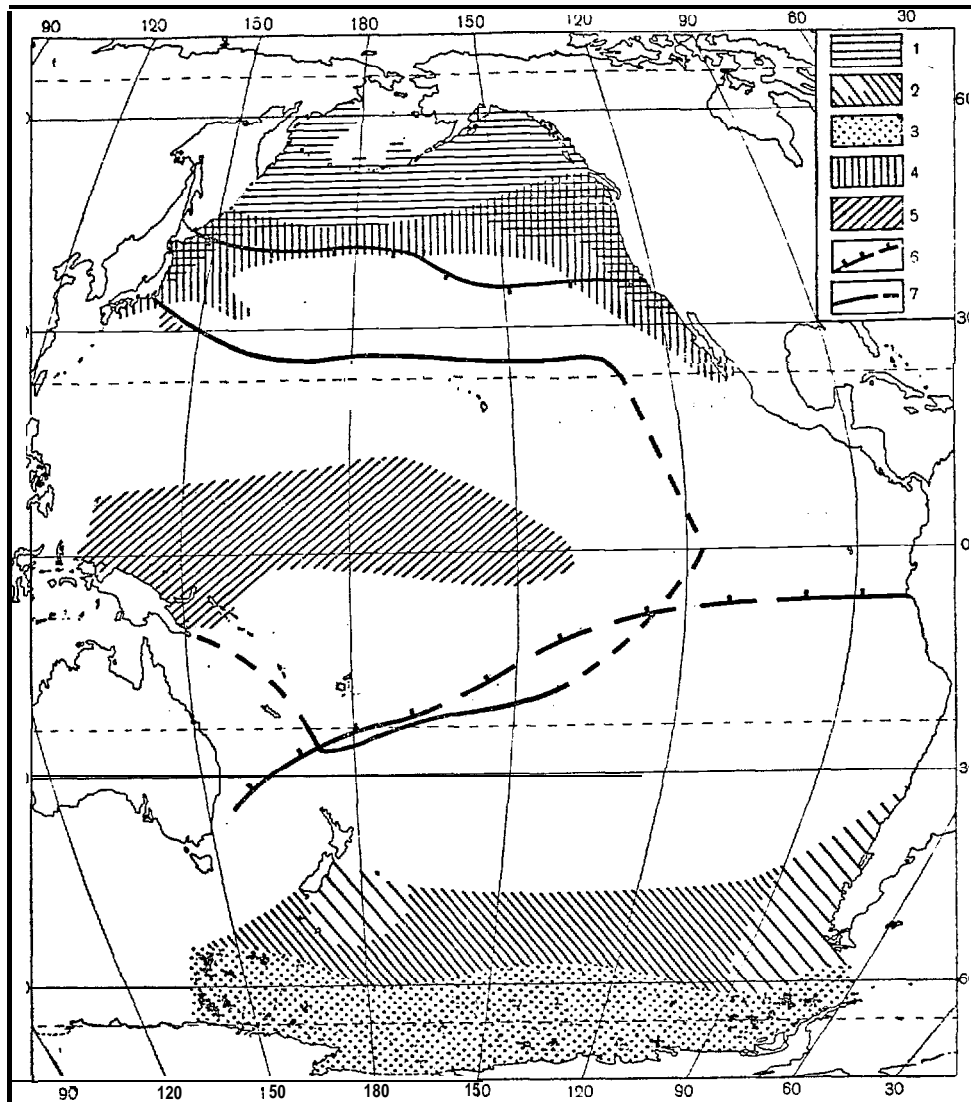
Figure III. 15.2.--Types of distribution of "Pacific Ocean myctophids:
1 - northern boreal (Stenobrachius leucopsarus); 2 - notal
(Electrons subaspera); 3 - Antarctic (Electrons Antarctica); 4 -
northern zones of mixed waters (Symbolophorus californiense); 5 -
western equatorial (Diaphus lutkeni); 6 - limit of distribution of
tropical latitude species (Myctophum affine); 7 - limit of
distribution of western tropical species (Myctophum spinosum +
lychnobium). (From Bekker 1967).

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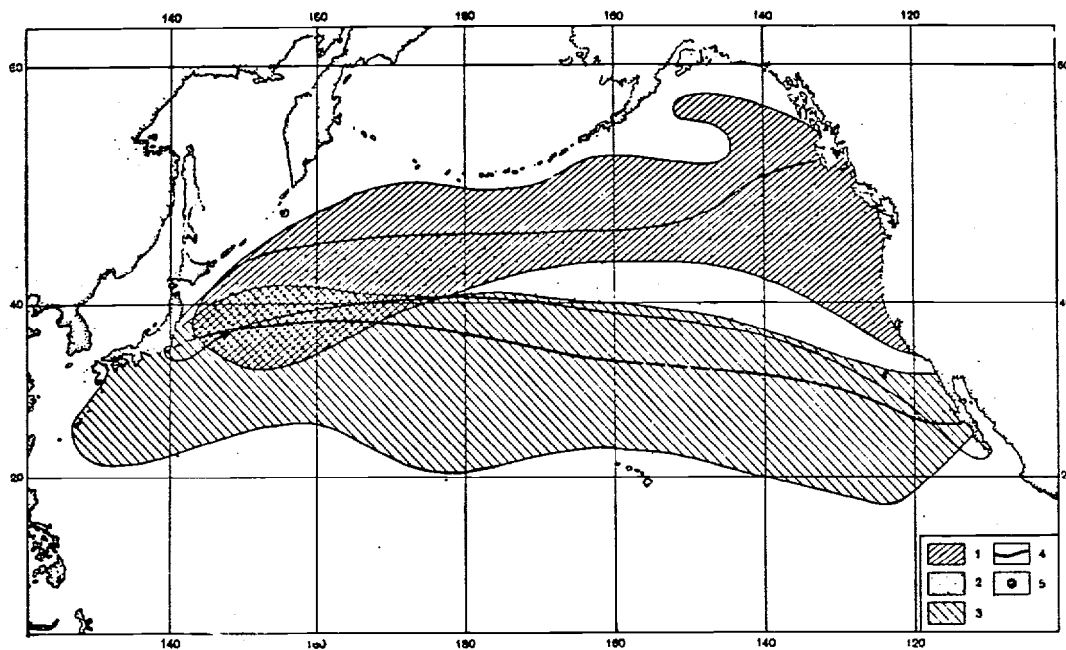
Figure 111.15.3.--Distribution of subsurface species of Myctophidae in the
   North Pacific. 1 - range of Tarletonbeania spp.; 2 - range of Symbolophorus
   (Myctophum) californiense; 3 - range of S. affine; 4 - northern boundary of
   distribution of the tropical lanternfishes S. evermanni, S. spinosum,
   S. brachygnathos; 5 - locality of collection of Tarletonbeania crenularis
   in September 1953 (from Parin 1961).
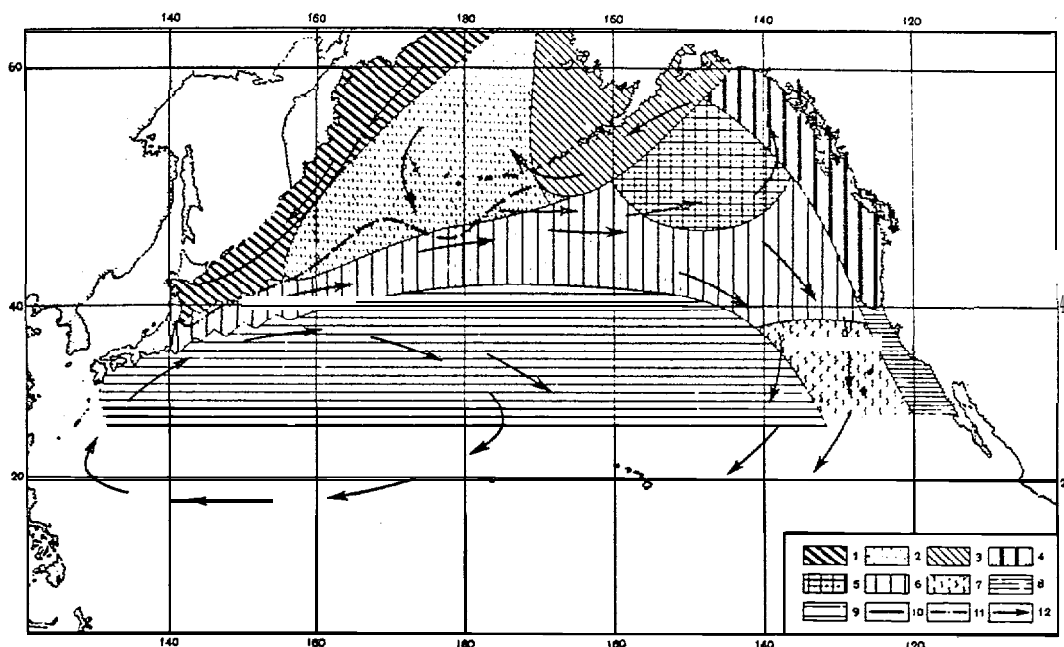
Figure 111.15.4.--Hydrological regions and currents of the-North Pacific.
   1 - Kurile-Kamchatka coastal region; 2 - western gyral; 3 - Alaskan coastal
   region; 4 - American coastal region; 5 - Alaskan gyral; 6 - Subarctic region:
   7 - transition region; 8 - California coastal region; 9 - central zone; 10 -
   extreme southeastern boundary of dichothermal waters at their point of minimal
   development; 11 - same at their point of maximal development; 12 - direction
   of currents in the winter. Hydrological regions (1-9) after Fleming (1955);
   boundaries of dichothermal waters (10-11) after Uda (1955). (From Parin 1961).

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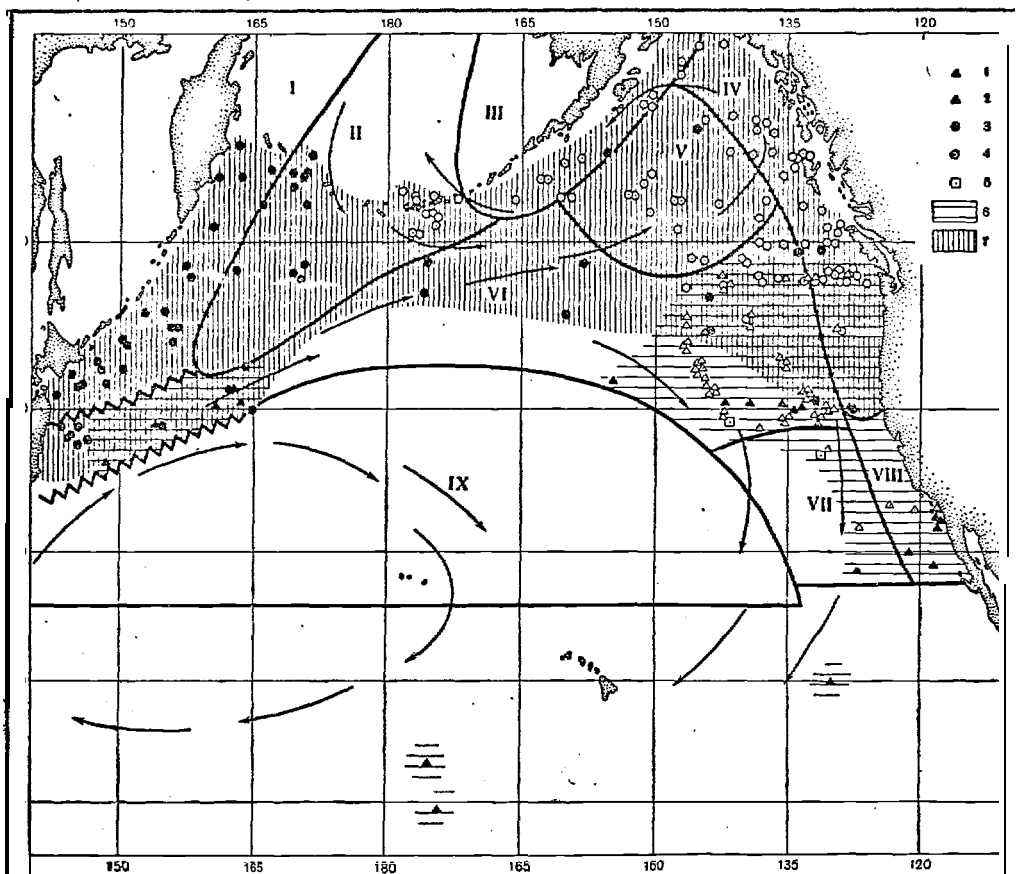
Figure 111.15.5 .--Distribution of North Pacific species of **Hierops**
(**Protomyctophum**). 1 - catches of **H. crockeri** by R/V VITYAZ; 2 -
the same from foreign expedition%; 3 - VITYAZ captures of H.
thompsoni; 4 - the same from foreign expeditions; 5 - captures of
E. rissoi (?), Aron, 1960; 6 - range of **H. crockeri**; 7 - range of
H. thompsoni. Hydrological regions after Fleming: I - **Kurilo-Kamchatka
coastal** region; 11 - western **gyral; III** - Alaskan coastal **region;**
I v - American coastal region; V - Alaskan **gyral;** VI - Subarctic
region; **VII** - Transitional; **VIII** - California coastal; IX - Central
Zone. Solid line - boundaries between regions; arrows show directions
, of currents in winter (from **Bekker 1963b).**

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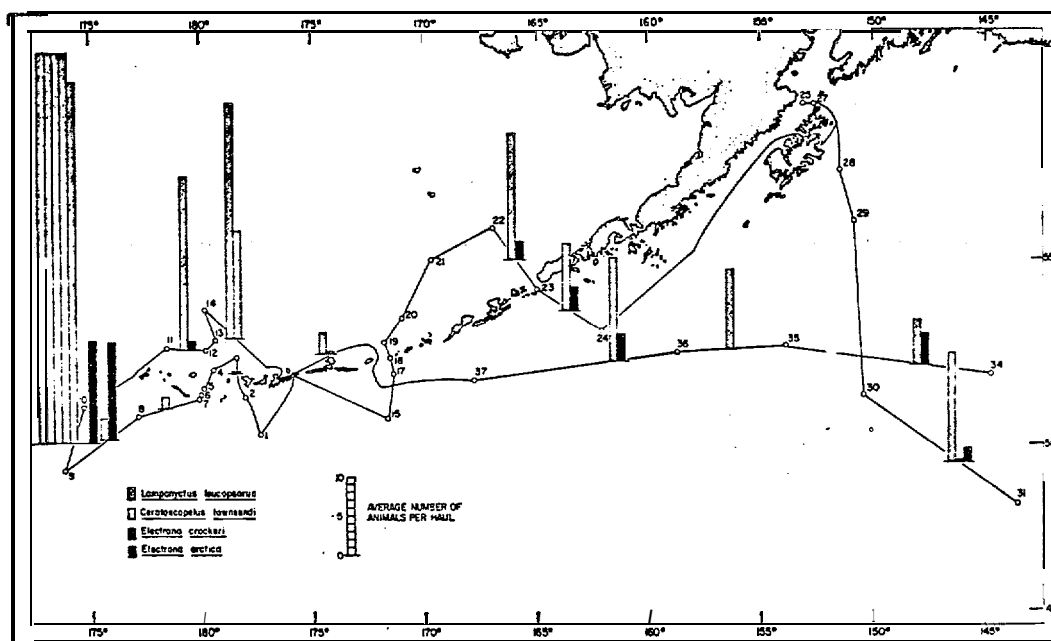
Figure 111.15.6.--Cruise tracks, **hydrographic** stations, and the average catch of **Lampanyctus leucopsarus, Ceratoscopelus** townsendi, Electrons **crockeri,** and E. arctica taken at depths of 30, 60, and 225 meters in the Gulf of **Alaska, Bering** Sea and Aleutian Islands areas on **BROWN BEAR** Cruise 176 (from **Aron** 1962).
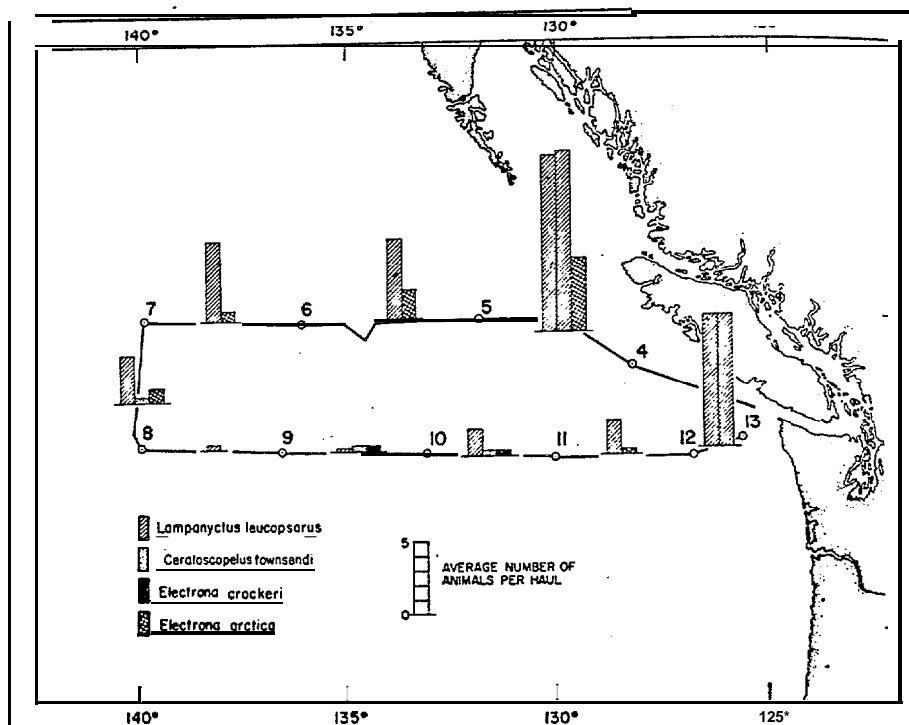
Figure 111.15.7 .--Cruise tracks, **hydrographic** stations, and the average catch of **Lampanyctus leucopsarus, Ceratoscopelus** townsendi, Electrons **crockeri,** and E. arctica taken at depths of 30, 60, and 225 meters off **British Columbia on** BROWN BEAR Cruise 202 (from Aron 1962).

Synopsis of Distribution and Biology of Species

Brief reviews of available information on biology and distribution of
selected species of Myctophidae found in the Bering Sea or Gulf of Alaska
are as follows:

Hierops thompsoni (Bigeye lanternfish)

The bigeye lanternfish, Hierops thompsoni, is variously known as Proto-
myctophum thompsoni (Bailey et al. 1970), Electrons thompsoni, Electrona
arctica, and Myctophum oculeum (Chapman 1937). The name Hierops thompsoni
is used in this report to conform -with the list of species names adopted
by the OCSEAP Program.

The bigeye lanternfish is found from Baja California north to the northern
Gulf of Alaska, the Bering Sea, along the Kurile Island-Kamchatka trench,
to northeastern Japan (Bekker 1963b, Hart 1973). It is associated with
the subarctic water structure, and individual occurrences in the Bering
Sea are associated with penetration into this region of a current branch
diverging from the Alaskan gyral, according to Bekker. Bekker also concluded
that it may occur in waters of lower temperature, having been caught north-
east of Honshu, Japan, when the water temperature was 1.4°C at 200 m and
1.05°C at the surface.

It is" assumed to live in the 200-400 m layer, and it possibly does not
rise to the surface at night. According to Chapman (1937), the species
was caught only outside the 100 fathom line in the waters of the Gulf
of Alaska and off British Columbia and Washington. British Columbia records
are 31-693 m (Hart 1973). Figure 111.15.8 shows the distribution of larvae
of Hierops (Electrons) in certain years as described by Le Brasseur (1970).

According to Chapman, its standard length is 16-43 mm, and Hart notes
it reaches a length of 70 mm.

No literature was found on biology, physiology, feeding habits, predators,
or other aspects of the life history of the species.

Tarletonbeania crenularis (Blue lanternfish)

The blue lanternfish, Tarletonbeania crenularis, is also known as Myctophum
crenulare. Some confusion exists regarding the species, because Hart (1973)
stated that there appear to be three populations around the North Pacific
basin with different average characters and little geographic overlap.
Mead (1953) listed Tarletonbeania taylori as a separate species, but Hart
considers it a population of T. crenularis. Bekker (1963a) found no dif-
ferences between the western T. crenularis and the eastern T. taylori.
Therefore, he stated they should be subspecies, T. crenularis- crenularis
and T. crenularis taylori. The ranges of the subspecies are divided by
the zone where the Aleutian Current diverges to form the Alaskan and the
California Currents (at approximately long 140%7), according to Bekker.
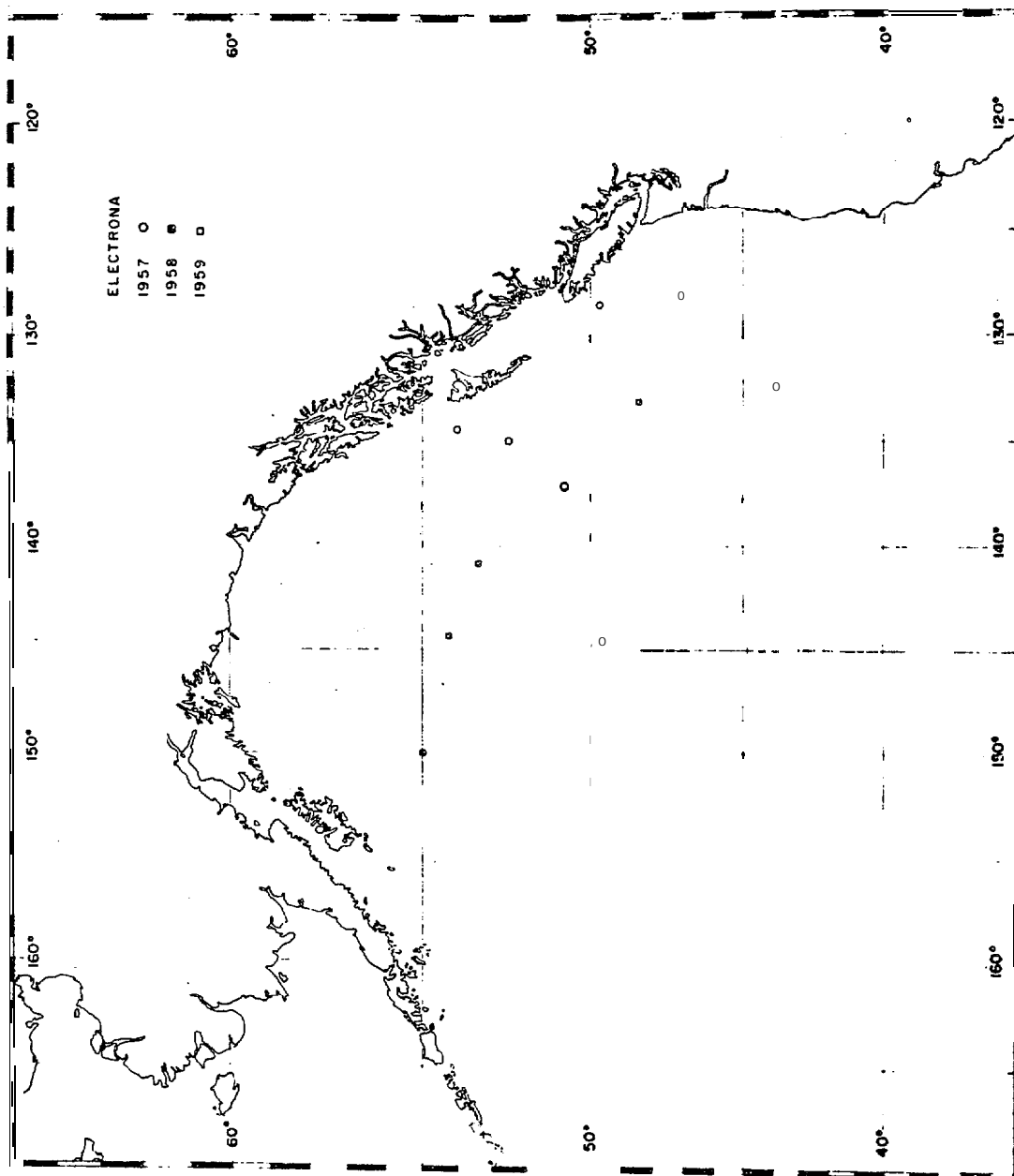
Figure III.15.8.—Distribution of larval samples of Hierops (Electrona) in the northeast Pacific Ocean, 1956–59 (from LeBrasseur 1970).

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The blue lanternfish is broadly distributed from the tropical mid-Pacific Ocean, off Mexico and California northward to Alaska, and to Japan (Hart 1973). Its distribution is closely associated with the current system of the North Pacific (Kuroshio, Aleutian, Alaskan, Californian), and it is absent in waters in the Kurile-Kamchatka region with an intermediate cold layer (Bekker 1963a) and in the central part of the Alaskan gyral (Parin 1961}. Parin stated that it is entirely confined within the limits of the subarctic water mass. Distribution for certain years is shown in Figures III.15.9 and 111.15.10.

It is found from the surface (at night) to depths of 710 m off British Columbia (Grinols 1965). The species is apparently sensitive to sharp fluctuations of water temperature, because a mass mortality occurred off the California coast when an unusual upwelling of water caused rapid cooling of the water (Aughtry 1953)..

Chapman (1937) reported that the standard length of T. crenularis in the Gulf of Alaska was 20-57.5 mm, and Bolin (1939) listed standard lengths of 50 specimens as being 18.1-79.2 mm. Maximum length is 127 mm (Hart 1973).

The food of T. crenularis is known to include euphausiids (Aughtry 1953), and albacore have been recorded as preying on T. crenularis off California and British Columbia according to Hart.

Ceratoscopelus townsendi (Dogtooth lampfish)

. This species is circumglobal in distribution. It has been recorded from southern California northward to at least lat 48.59°N, long 144.21ow. While fairly common to the south, it is rare off British Columbia. It has been recorded off Japan and Hawaii and is generally considered as a lanternfish that is to be found in the upper waters (Hart 1973). Depths of capture have ranged from 29 m to 403 m.

Diaphus theta (California headlightfish)

Other common names of the California headlightfish include white-spotted lanternfish and theta lampfish (Hart 1973). It also has been identified, among other scientific names, as D. rafinesquei or D. rafinesquii.

The species occurs from southern California northward off Washington, Oregon, and British Columbia, to the Gulf of Alaska and in the tropical mid-Pacific Ocean at depths of 20 to 1690 m (Parr 1929, Chapman 1937, Wilimovsky 1954, McAllister 1961, Grinols 1965, Taylor 1968). Pelagic trawling by the Russians in the central and eastern Pacific Ocean in 1965 showed the species was distributed at 35-450 m but predominated in the 300-450 m layers (Novikov 1970). Chapman (1937) reported it was taken in deep water outside the 100 fathom (182 m) line off the coast of Washington to south of Kodiak Island, Alaska. Larvae have been taken off California (Hart 1973).
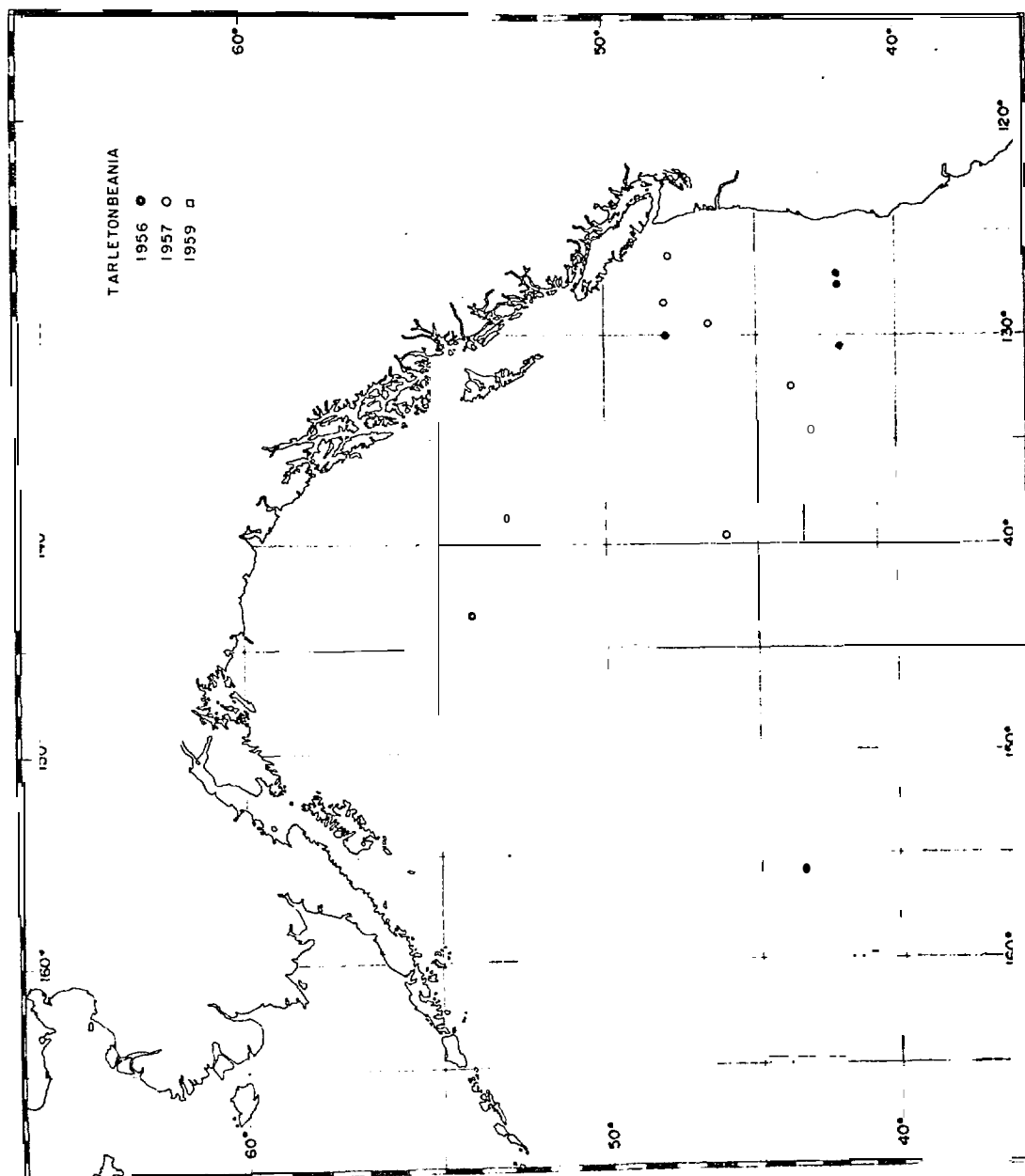
Figure III.15.9.—Distribution of larval samples of _Tarletonbeania_ in the northeast Pacific Ocean, 1956–59 (from LeBrasseur 1970).

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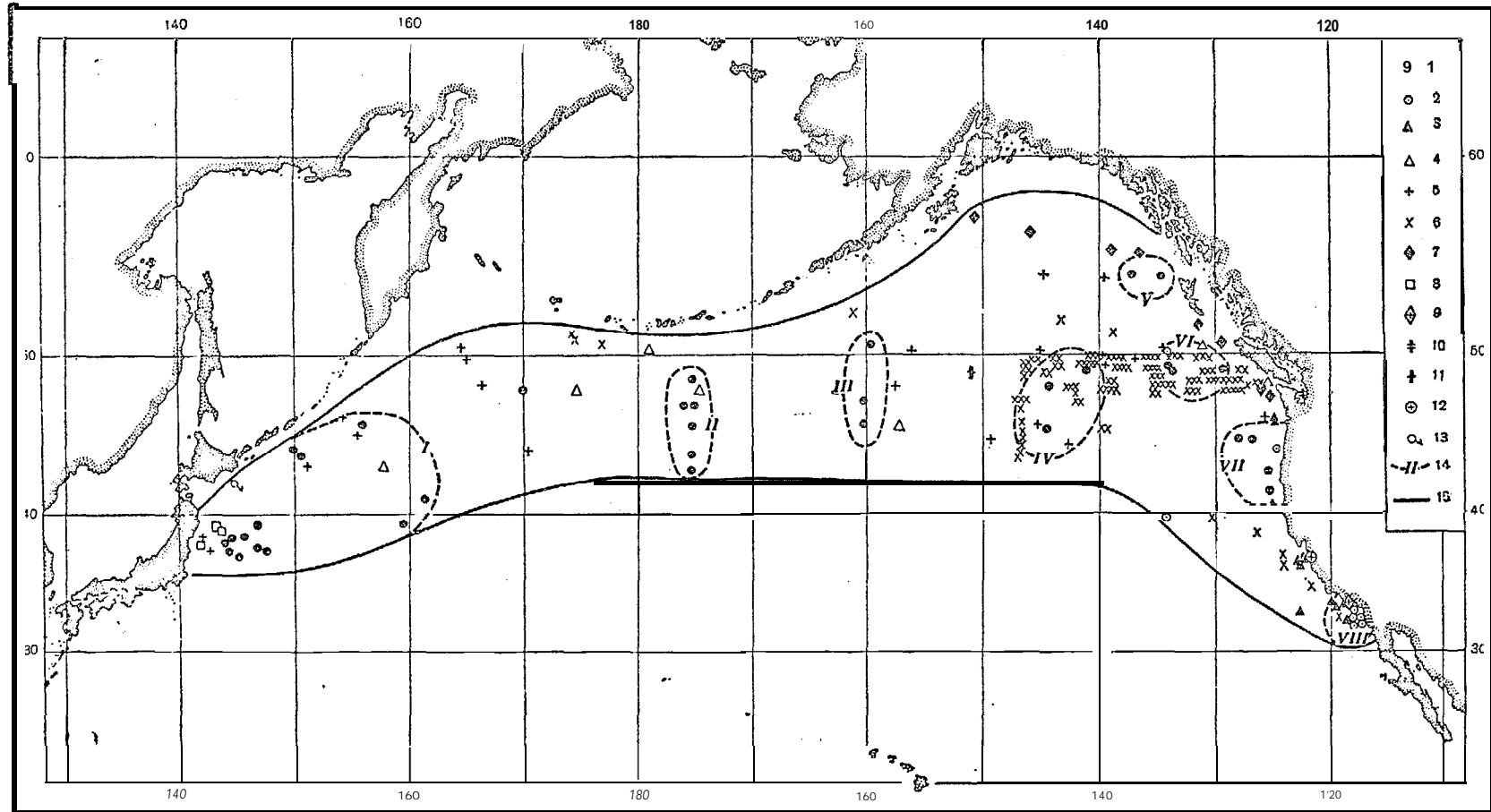
Figure 111.15.10.—Distribution of Tarletonbeania crenularis plotted from: 1- collections of exploratory vessel VITYAZ, 2 - data from Scripps Institution of Oceanography, 3 - Bolin (1939), 4 - Kobayashi (1958), 5 - Wisner (1959), 6 - Aron (1960). 7 - Chapman (1940), 8 - Mead (1953), 9- Gilbert (1915), 10 - Kincaid (1919). 11 - Bean (1882), 12 - Aughtry (1953). 13 - Iwai and Okamura (1960), 14 - limits of regions according to which Bekker (1963a) combined data, 15 - limits of distribution (from Bekker 1963a),

It is a small fish that attains a maximum length of about 12 cm. Various ranges reported are standard lengths of 4.5-7.3 cm in the Gulf of Alaska and off Washington and British Columbia (Chapman 1937), and total lengths of 4-12 cm in the central and eastern North Pacific (Novikov 1970).

D. theta feeds on various crustaceans, including euphausiids, copepods, and amphipods (Paxton 1967, Collard 1970, Novikov 1970).

Lampanyctus regalis (Pinpoint lampfish)

Other common names of this species are pinpoint lanternfish and small-eyed lanternfish (Hart 1973). It is distributed from off Mexico northward to the Gulf of Alaska and the Kurile Islands at depths of 99-1,630 m (Wilimovsky 1954, Grinols 1965). Aron (1959) found specimens in Isaacs-Kidd midwater trawls west of the Aleutian Islands.

It is known to reach a length of at least 19 cm according to Hart. Food of the species off California was euphausiids (Collard 1970).

Lampanyctus ritteri (Broadfin lampfish)

Broadfin lanternfish is another common name of this species. It is found off the coast of California northward through British Columbia at depths ranging from 223 m to 1375 m (Aron 1958, Grinols 1965, Taylor 1968). Length is up to 19 cm (Hart 1973); 24 specimens off California were 2-10 cm in standard length (Bolin 1939). The broadfin lampfish is known to feed on Sagitta, young fish, amphipods, copepods, and euphausiids (Gilbert 1915, Grinols 1965, Paxton 1967, Collard 1970).

Notoscopelus resplendens (Patchwork lampfish)

This species is also known as the patchwork lanternfish. It is found in all parts of the world. According to Grinols (1965), it occurs in the eastern Pacific from California northward to at least lat 52.17*N, long 133.1OW. Off British Columbia and Washington it has been caught at depths of 29 to 60 m, but it probably is found at greater depths (Hart 1973).

Stenobrachius leucopsarus (Northern lampfish)

The northern lampfish is sometimes called the northern lanternfish or small-finned lanternfish (Hart 1973). The scientific name Lampanyctus leucopsarus is often used; other names have been L. leucopsarum, Myctophum leucopsarum, M. nannochir, and S. leucopsarum (Bolin 1939).

This fish was the most frequently collected species of larval fish in the northeast Pacific in sampling in 1956-59 (LeBrasseur 1970), and it was the most abundant fish taken by Aron (1962) in midwater trawl samples north of 45°N across the Gulf of Alaska to the Aleutian Islands. It also was the most abundant species in the plankton collection of the International Halibut Commission, according to Chapman (1937).

It was found from southern California to Alaska, the Bering Sea, off Kamchatka
and Japan (Kulikova 1960, Grinols 1965). It is considered characteristic
of upper layers of the bathypelagial up to 500 m, but it is found as deep
as 6,700 m (Kulikova 1960, Novikov 1970). Aron (1962) found it was most
numerous in hauls at 30 m north of 50°N and at 60 m south of that latitude.
Fedorov (1973a) lists the depth range as 0-2,970 m in the Bering Sea,
Novikov noted it was found at 50-700 m in the central and eastern Pacific,
and it has been found at various depths from the surface to 2,900 m off
California, Oregon, Washington, and British Columbia (Gilbert 1895, Grinols
1965, Barraclough 1967). Figure 111.15.11 shows the distribution of S.
(Lampanyctus) leucopsarus and two other species of the genus in the North
Pacific Ocean. Distribution of larval Stenobrachius in the northeast Pacific
from sampling in 1956-59 is shown in Fig. III.15.12.
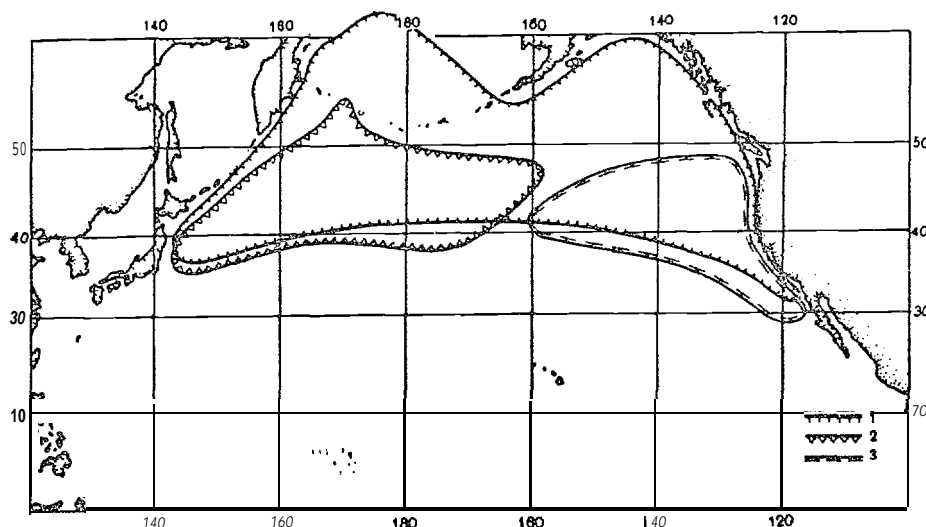
Figure 111.15.11.--Distribution of some lampanictids in the North
    Pacific: 1 - Stenobrachius (Lampanyctus) leucopsarus, 2 - S. (L.)
    jordani, 3 - S. (L.) ritteri (from Parin 1961).

Smoker and Pearcy (1970), using samples collected off the coast of Oregon,
determined that spawning occurs from December to March, although it may
occur earlier off the coast of California. Growth is approximately linear
at 1.59 mm (standard length) per month during the second, third, and fourth
years of life. Yearlings average about 23 mm, two year olds 41 mm and
three year olds 59 mm. Otolith studies indicated that some might reach
an age of eight years, although confidence in the aging system diminishes
after 4 or 5. Maturity occurs at 4 years.

Smoker and Pearcy also determined that recruitment of young size groups
is seasonal, because 20-25 mm individuals appeared in largest ProP[ortions]
in trawl samples in winter, presumably about 8 months after spawning.
This is somewhat similar to Novikov's (1970) statement that S. leucopsarus
and Diaphus theta were taken principally in autumn in the Vancouver-Oregon
region. LeBrasseur's (1970) work off British Columbia showed a seasonal
variation in the abundance of larvae with an annual low in the period
October through December, a peak in the December to February period, and
a decline to a low but steady level for the period June through September.
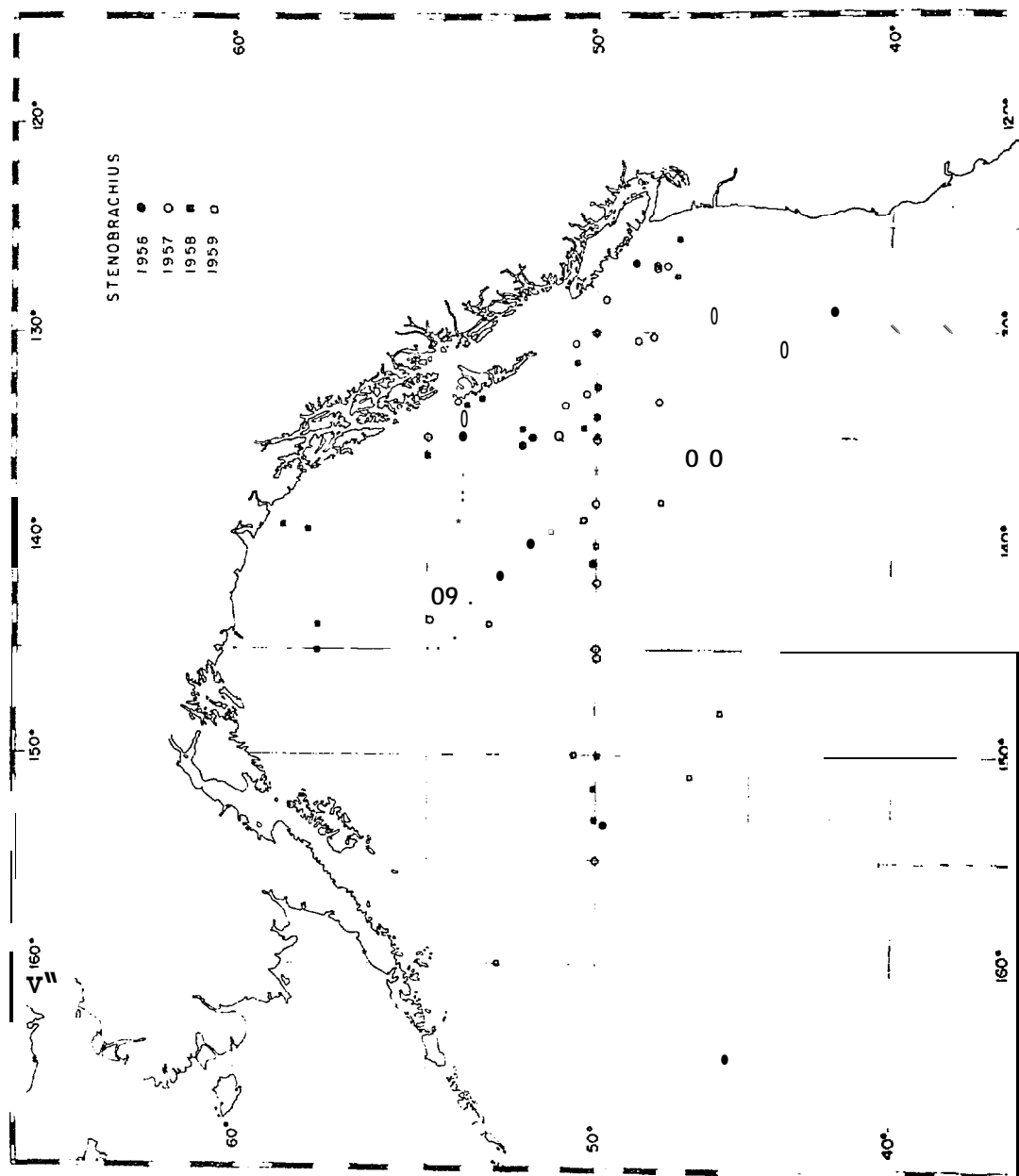
Figure III.15.12.--Distribution of larval samples of Stenobrachius in the northeast Pacific Ocean, 1956-59 (from LeBrasseur 1970).

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The maximum" length attained is 12.7 cm according to Clemens and Wilby (1961), but Smoker and Pearcy estimated the theoretical maximum size off Oregon was 8.5 cm. Kulikova (1960) caught specimens of 3.3 to 10.5 cm off the U.S.S.R. compared to lengths of 1.7 to 8.8 cm found by Bolin (1939) off California. Specimens taken by Chapman (1937) in Gulf of Alaska waters had lengths without caudal fin of 1.9 to 11.4 cm.

'L'he food of S. leucopsarus includes fishes, copepods, and euphausiids (Collard 1970). Known predators are yellowtail rockfish and salmon (Pereyra et al. 1969), cod in the Bering Sea (Nikol'skii 1954), and fur seals (Taylor et al. 1955).

Symbolophorus californiense (Bigfin lanternfish)

The bigfin lanternfish is also known by the scientific name, Myctophum californiense, and the common name of California lanternfish. It has been found from Baja California northward off California, Oregon, Washington, British Columbia and Alaska, to Japan, at depths of 31 to 1,560 m (Mead and Taylor 1953, Aron 1958, Grinols 1965).

According to Fitch and Lavenberg (1968), this species (off California) reaches a maximum size of about 12.7 cm and weighs slightly more than 14 g. A 10 cm fish was five years old, as determined from otoliths, indicating that a maximum age may be about seven years. They spawn during the spring and summer. The fish is easily attracted to lights at night, may be captured by dipnets, and is commonly caught in midwater trawls.

It feeds almost exclusively on small crustaceans such as copepods and euphausiids (Fitch and Lavenberg 1968, Collard 1970). Predators include albacore, jack mackerel, rockfishes, cephalopods, birds, and marine mammals, according to Fitch and Lavenberg.

Predators of the Myctophidae

A review of the literature indicates that lanternfishes are consumed by a number of fishes and mammals, including commercially important species (Table 111.15.1), and by birds. These small fishes, although they are not pursued by commercial fishermen, are valuable for their vital contribution to the food chain.

Most of the reports of predation on myctophids have come from research done on the feeding habits of the fur seal (Callorhinus ursinus). Lanternfishes are a significant part of the diet of the fur seal at times. Seven species of myctophids were found in fur seal stomachs in May and June off Japan: Ceratoscopelus townsendi, Diaphus nanus, D. latus, Stenobrachius (Lampanyctus) leucopsarus, Symbolophorus (Myctophum) californiense, and Tarletonbeania taylori (Taylor et al. 1955) . Wilke and Kenyon (1954) found that--a 'single-species, Notoscopelus japonicum, formed 99 percent by volume of the lanternfishes consumed and 69 percent of all food eaten by fur seals off Japan in late March, April, and May 1952 when seal migration was at its height. Composition of fur seal food is not always the same and varies from year to year and season to season.

Table 111.15.1.--Predators of fishes of the family Myctophidae in the North Pacific Ocean.

Myctophid species	Predator	Area	Source
Myctophidae spp.	Fur seal (Callorhinus ursinus)	California	1
	" " "	Washington, Gulf of Alaska	5
	" " "	Okhotsk Sea	1
	" " "	Japan	8,9,13
	Jack mackerel (Trachurus symmetricus)	California	2
Ceratoscopelus townsendi	Fur seal	Japan	12
Diaphus spp.	Fur seal	Japan	7,9,14
	Cod	Japan	14
Diaphus latus	Fur seal	Japan	12
Diaphus nanus	Fur seal	Japan	12
Notoscopelus Spp.	Dan porpoise (Phocaenoides dalli)	Japan	14
Notoscopelus elongatus	Fur seal	Japan	7,9
Notoscopelus japonicum	F u r seal	Japan	12,13
Stenobrachius (Lampanyctus) spp.	Cod	Japan	14
Stenobrachius (Lampanyctus) leucopsarus	Cod	Bering Sea	4
	Fur seal	Japan	12
	Widow rockfish (Sebastodes entomelas)	Washington, Oregon	Lo
	Yellowtail rockfish (Sebastodes flavidus)	Washington, Oregon	10
Stenobrachius (Lampanyctus) nannochir	Fur seal	Bering Sea, Gulf of Alaska	1 , 8
Symbolophorus (Myctophum) californiense	Fur seal	Eastern Pacific, Japan	7 / 12
Tarletonbeania crenularis	Sablefish (Anoplopoma fimbria)	Washington, Oregon	3
	Fur seal (Callorhinus ursinus)	California, Oregon	6,7
	Soupfin shark (Galeorhinus zyopterus)	Washington, Oregon	3
	Coho salmon (Oncorhynchus tshawytscha)	Washington, Oregon	3
	Sperm whale (Physeter catodon)	California	11
	Blue shark (Prionace glauca)	Washington, Oregon	3
	Jack mackerel (Trachurus symmetricus)	Washington, Oregon	3
Tarletonbeania taylori	Fur seal.	Japan	12
	Dan porpoise (Phocaenoides dalli)	Japan	14

References: (1) Arsenev and Fedorov 1964 (cited by Geptner [Heptner] et al. 1976), (2) Fitch 1956a, (3) Grinols and Gill 1968, (4) Nikol'skii 1954, (5) National Marine Fisheries Service 1970, (6) North Pacific Fur Seal Commission 1962, (7) ibid. 1969, (8) ibid. 1971, (9) ibid. 1975, (10) Pereyra, Pearcy, and Carvey 1969, (11) Rice 1963, (12) Taylor, Fujinaga, and Wilke 1955, (13) Wilke and Kenyon 1954, (14) Wilke and Nicholson 1958.

Table 111.15.2.—Myctophidae in stomach contents of the northern fur seal, Callorhinus ursinus, in the eastern North Pacific Ocean.

Area	Time	Volume (cc)	Percent	Stomachs with food	Myctophid frequency	Reference
Oregon	Winter (February 1959)	--	.-	3	--	1
	Spring (Mar.-Apr. 1959)	647	4 . 5	28	4	1
Washington and British Columbia	Spring (Mar.- May 1966)	18	0.1	98	1	2
	Winter (Dee.-Feb. 1968)	55(-1	0.7	251	4	5
Gulf of Alaska	Spring (Apr.-May 1958)	--	--	161	--	1
	Summer (June-July 1958)	--	--	16	--	1
	Spring (May 1968)	trace	--	77	1	4
	Summer (June-Aug. 1968)	--	--	95	.-	,4
Southeast Alaska	Winter (Feb. 1958)	--	--	33	--	1
	Spring (Mar.-Apr. 1958)	222	0.2	120	2	1
Western Alaska	Summer (June 1958)	--	--	52	--	1
	Summer (June-July 1968)	--	--	91	--	4
Bering Sea and Unimak Pass	Summer (June-Aug. 1960)	22	--	229	1	1
Bering Sea	Summer (July-Sept. 1963)	15	---	816	2	3
	Summer (June-Aug. 1968)	--	--	141	--	4

References: (1) North Pacific Fur Seal Commission 1962, (2) ibid. 1969, (3) ibid. 1971, (4) ibid. 1975, (5) National Marine Fisheries Service 1970.

Wilke and Kenyon (1954) expected that because lanternfish were an important part of the diet of fur seals off Japan in the same latitude as collections from California, the fishes would occur in fur seal stomachs off California. None were found, although other observers have seen fur seals pursuing lanternfish in California waters. The species Symbolophorus (Myctophum) californiense was reported from fur seal stomachs in the eastern Pacific for the first time in 1966 (North Pacific Fur Seal Commission 1969). Table 111.15.2 lists the occurrence or lack of myctophids in fur seal stomachs sampled in the eastern North Pacific Ocean. The data show that the amount of myctophids consumed by fur seals in the Gulf of Alaska and Bering Sea is apparently small in relation to other fish species. No firm conclusion should be made, however, because the fur seal is an opportunistic feeder and lack of occurrence in stomachs might be because of time or place of sampling.

The commercial fish species that have been found to prey on Myctophids (Table 111.15.1) include coho salmon, sablefish, saury, and soupfin shark (Grinols and Gill 1968); jack mackerel (Fitch 1956a); and cod (Nikol'skii 1954). Sampling of food of rockfishes in Astoria Canyon off the mouth of the Columbia River showed that Stenobrachius leucopsarus composed 75 percent of the food volume of the yellowtail rockfish, Sebastodes flavidus, and 54 percent of the food volume of the widow rockfish, S. entomelas (Pereyra, Pearcy, and Carvey 1969).

The list of fishes and mammals that prey on lanternfishes is obviously incomplete, but the review of literature does indicate that Myctophids may be of substantial importance to some valuable species.

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PACIFIC SAURY (Cololabis saira)
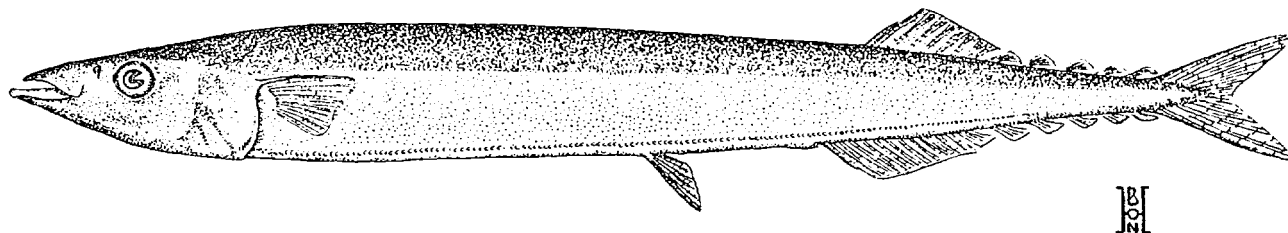
Figure 111.16.1.--Pacific saury, Cololabis saira (from Hart 1973).

IDENTIFICATION

The Pacific saury belongs to the order Atheriniformes, Family Scomberesocidae.
The saury of the northeastern Pacific has, in the past, been classified as a
species separate from those found near the Asian coast. The species were term-
ed Cololabis brevirostris (Peters) and Scomberesox saira (Brevoort), respec-
tively. The unity of the species Cololabis saira (Brevoort) was established
by Hubbs in 1916 (Grinols 1965, Sokolovskii 1969).

The Pacific saury is known by a variety of common names:

United States and Canada:	Pacific saury, saury, needlefish
U.S.S.R.	Saira, makeleshchuka skumbreshchuka (Berg et al. 1949)
Japan	Sanma, saira, bansho, banjo, kado, marukado, saire, sairenbo, saera, tamano sayori, saza, sazameio, sairaiwashi (Inoue and Hughes 1971)

DISTRIBUTION

Sauries are found in most temperate and subtropical seas around the world.
They are typically oceanic and no part of their life cycle is associated with
the coastal environment, although at times they have been found as far inshore
as brackish water estuaries. Their range is limited in all cases by existing
temperature regimes ranging from 6° C to 24° C, with a preferred range of 12-
18° C (Parin 1958, 1960; Hart 1973).

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The Pacific saury is found across the entire North Pacific ocean between lat 19° N and lat 58° N (Sokolovskii 1969). It is also found in the East China Sea, the Sea of Japan, the Sea of Okhotsk, along the coasts of Japan to the Ryukyu Islands, the Gulf of Alaska south to Baja California, north of the Hawaiian Islands to the Aleutian chain, and occasionally, in the Bering Sea (Kasahara 1961) (Fig. 111.16.2).

— — — Limits of winter distribution
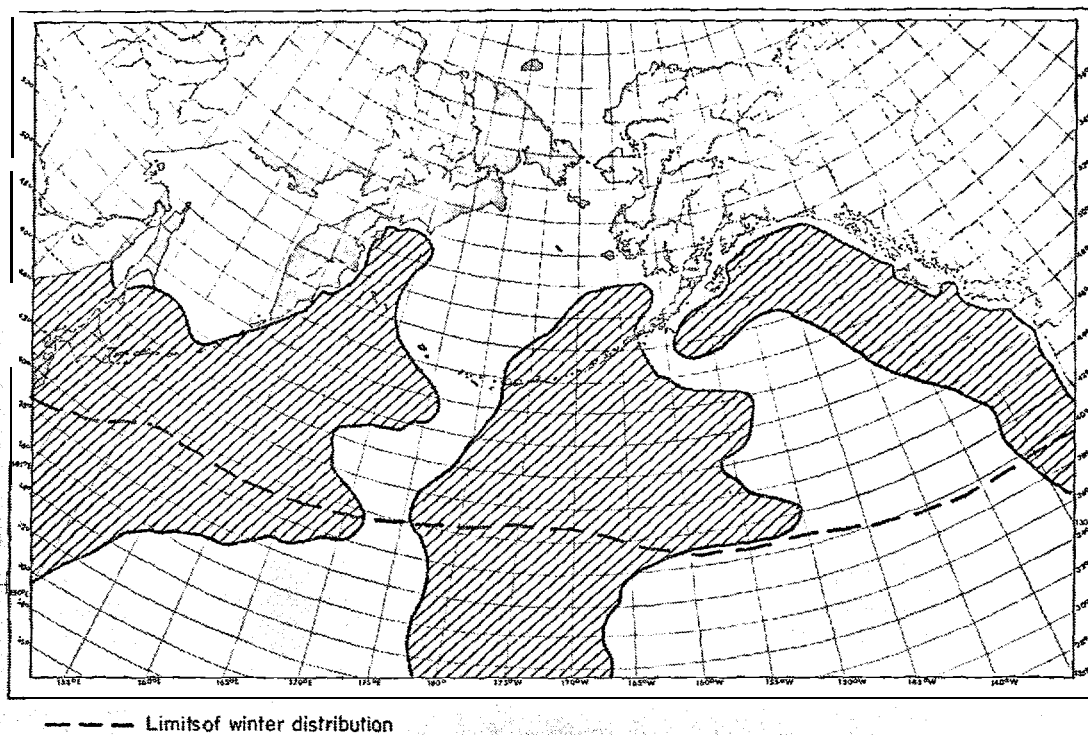
Figure 111.16.2.--Distribution of Pacific saury (compiled from information in Kasahara 1961; Novikov 1966; Parin 1967; Kobayashi, Wake, and Naito 1968).

Sauries are most commonly found schooling near the surface, but individuals have been found as deep as 180 m.

The uniformity of the offshore oceanic environment points to the existence of a single North Pacific stock with the only distinction into subpopulations arising from geographical separations (Kasahara 1961). Soviet investigators have found maximum separation areas between long 165° E and 170° E and between long 155° W and 150° W (Sokolovskii 1969).   In the past, the localized nature of saury population studies led to the belief held by some Japanese investigators that 2-3 separate stocks of sauries existed (Hotta 1964 cited by Trumble 1973, Kobayashi 1968 cited by Inoue and Hughes 1971). The currently accepted separation of a single stock into three subpopulations, advanced by Novikov and Chernyi (1967) and Sokolovskii (1969), has been confirmed by studies on indicator parasites, morphometric characters, as well as differences in length, fecundity and age at maturity. Sokolovskii named them as Asian, Aleutian and North American subpopulations.

Sauries of the North American subpopulation occur as far south as Baja California.   However, their 'abundance sharply decreases south of Cape San Lucas. Maximum concentrations have been observed in the area 40-120 miles offshore. Off California, medium sized sauries are found farther inshore than juveniles and larvae, while adults occur in the areas farthest offshore (Frey 1971).

As a general rule, it may be stated that densities and overall abundance increase with decreasing latitutdes while individual size and dispersion increases with latitude (Frey 1971, Hughes 1974) (Fig. 111.16.3).

Distribution in the Gulf of Alaska

The distribution of saury in the Gulf of Alaska is of a definitely seasonal character, dominated by seasonal temperature changes. In early summer, sauries of the North American subpopulation migrate north from their wintering range (lat 26°-40° N) and their spawning range (lat 33'-45° N). By July, juveniles migrate north to lat 54° N and westward to the eastern limits of the range of the Aleutian subpopulation (Inoue and Hughes 1971). As the season progresses, schools composed of mixed age groups are scattered throughout the Gulf.   Schools occur in heaviest concentrations in areas with 15°-17 C surface temperatures, near areas of upwelling with strong surface influence, and near sharp thermal fronts (Trumble 1973).   The position and movements of these thermal fronts dictate the densities of concentration as well as local migratory movements.   Because most currents in the northeastern Pacific are more drift and streamline, no heavy concentrations similar to those found in the western half of the North Pacific have been observed.   Instead, according to Trumble, saury concentrations are associated primarily with areas of upwelling and current shifts.   According to Novikov (1966b), if the North American saury behaves in a manner similar to the Asian, concentration densities would reach a maximum in the Gulf during August and September at the end of the summer feeding period and the beginning of the southward autumn spawning migration.

Distribution in the Bering Sea

The Pacific saury is one of the very few epipelagic species of fish found in the Bering Sea.   The distribution and stock composition of Bering Sea sauries
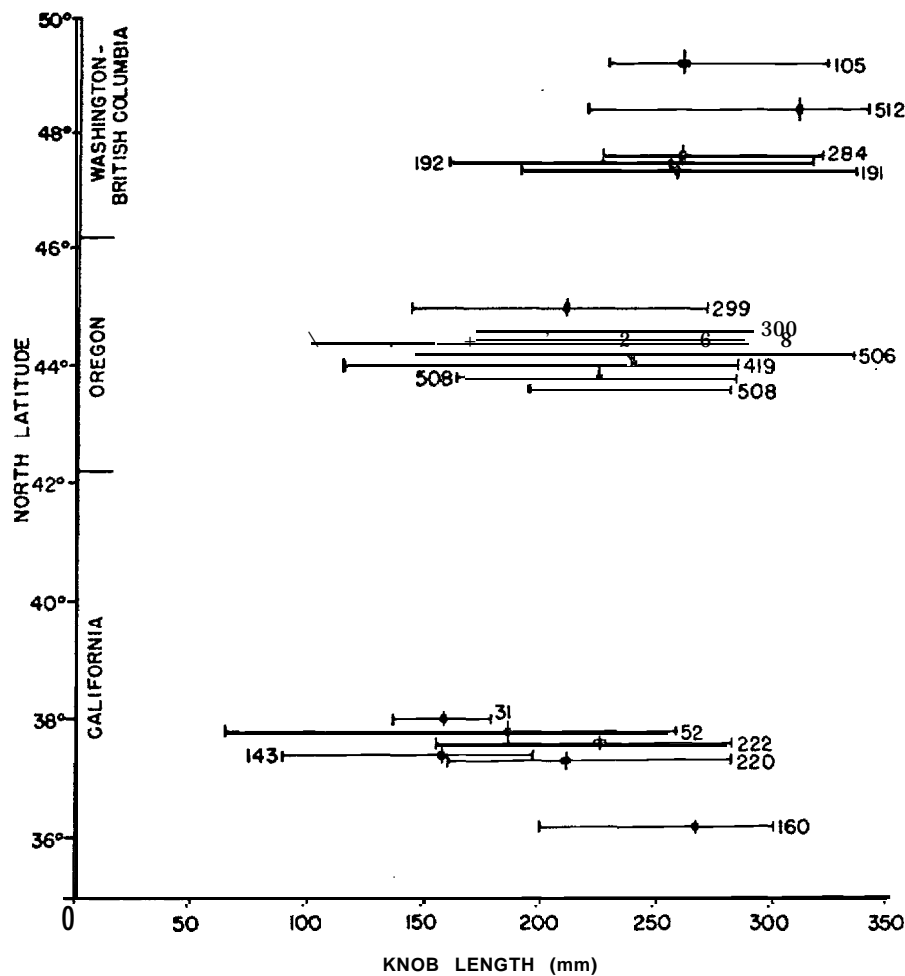
Figure 111.16.3.--Lengths (mean, range, and standard deviations of mean) of
eastern pacific saury plotted against latitude of capture.
Numb ers indicate sample size per school (from Hughes 1974).

have not been studied as yet; however, it is assumed that they form a part
of the Aleutian subpopulation. Aleutian sauries undertake a northward feeding
migration in the area between long 165° W and 180° W in early spring (Fedorov
1973 a).They have been observed in the Bering Sea in years with a sizeable
rise in surface temperatures and have been occasionally caught in salmon
gillnets (Faculty of Fisheries, Hokkaido University 1964).

LIFE HISTORY

Very little is known about the North American subpopulation which seasonally
enters the Gulf of Alaska, and almost nothing is known about the Aleutian
population which enters the Bering Sea. Consequently, information on the
life history and behavior of Asian Pacific saury is included to help fill
gaps in present knowledge.

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Reproduction

The Pacific saury matures generally in its third year of life, although maturation may occur as early as its second year or as late as its fourth (Kasahara 1961, Sokolovskii 1969, Hughes 1974). North American Pacific sauries may mature at any size over 22 cm (occasionally 18-20 cm) while Asian fishes are usually larger at maturity (over 25 cm) (Novikov 1973). No sexual dimorphism has been detected by the various investigators in any of the subpopulations and, further, the overall spawner ratio, although variable in area and time, has been long assumed to equal unity (Kotova 1958, Kasahara 1961, Smith et al. 1970).

The fecundity of the Pacific saury is relatively low when compared to other pelagic spawners of similar size in the area, e.g. sardine, anchovy, herring. However, the effects of low fecundity, in the case of saury, are largely offset by the fact that saury larvae hatch at a relatively advanced stage of development. Egg maturation in gravid females proceeds in stages as evidenced by the trimodal distribution of egg size and maturity stage. Egg diameter modes are 0.6 mm, 1.1 mm, and 1.9 mm, and the maturation interval between batches is approximately two months (Odate 1956).

Saury females spawn 1,000 to 4,500 eggs per batch (Sokolovskii 1969). Because of the two month egg maturation interval, there exists the possibility for up to six spawnings per year. United States investigators have suggested that sauries along the coast of North America spawn only twice (spring and fall) in their first year of spawning and every two months in subsequent years (Inoue and Hughes 1971). Increased post spawning mortality limits sauries to a total of 6-7 spawnings, however, because few live longer than one year past their first spawning. According to SokoLovskii (1969), fertility (as a factor of fecundity, spawner size and Longevity) of Asian Pacific saury is 1.5 to 2.0 times greater than that of North American sauries.

Sauries spawn in offshore areas along the Kuroshio, North Pacific and Califor- . nia Currents and their continuations which form the main part of the sauries' range. Their eggs and larvae have been found throughout their range, at times over 1,000 miles offshore (Sokolovskii 1969, Inoue and Hughes 1971). Spawning occurs in winter as far south as the Ryukyu Islands, north of Hawaii, and in southern California. In summer they have been observed spawning to the northern limits of their range (Sokolovskii 1969).

Although the spawning season is very extensive, it is notable that in spite of the varying temperatures and hydrological regimes, the peak spawning periods for the various subpopulations are almost coincidental. Furthermore, as a rule, older fish spawn first, during autumn and winter, followed by the younger spawners in spring (Sokolovskii 1969, Trumble 1973). The fact that most younger individuals spawn in spring, coupled with the increased post-spawning mortality, helps explain the predominance of sauries bearing spring-born characters in the various subpopulations (Hughes 1974). Spawning peaks occur in February-March in the western Pacific; March-April in the central; and April-June in the eastern North Pacific (Larkins 1964, Novikov 1966b, Frey 1971, Sokolovskii 1972).

Pacific sauries spawn in dense concentrations at the surface at all hours, with peaks at midday and midnight (Inoue and Hughes 1971). The primary determinants for the formation of spawning concentrations appear to be temperature, followed by the availability of suitable substrate, usually floating seaweed (especially _Sargassum_) or any concentration of floating objects with branched or frayed surfaces. In the central Pacific, pelagic barnacles and salps, found in spring along the subarctic convergence, are used as a substitute substrate (Kotova 1958, Kasahara 1961, Smith et al. 1970, Inoue and Hughes 1971). Following the formation of concentrations, spawning is usually triggered by any abrupt rise in temperature. Minimum spawning temperature observed for North American Pacific sauries is 11° C; for Aleutian 13° C; and for Asian 14° C (Novikov 1966b, Sokolovskii 1972) (Fig. 111.16.4).
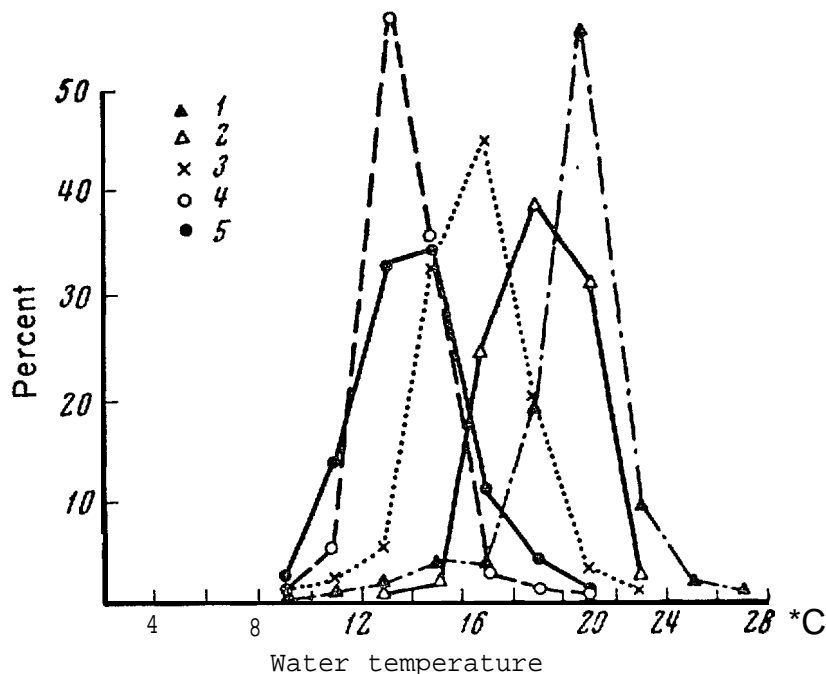
Figure 111.16.4.--Temperature regime of saury spawning in different regions of the Pacific. 1- Temperature distribution of saury larvae in the Kuroshio waters (Hattori 1967), 2- temperature distribution of saury larvae in the Kuroshio waters (Novokov 1967) , 3- temperature distribution of central Pacific saury larvae and young (Sokolovskii 1972), 4- temperature distribution of saury eggs along the North American coast (Ahlstrom and Casey 1966), 5- temperature distribution of saury larvae and young along the North American coast (Sokolovskii 1972). (Figure from Sokolovskii 1972).

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Pacific saury eggs are pelagic. Their shape is unusual (ovoid), however,
and they have, at times, been erroneously classified as demersal. The eggs
adhere to each other and any floating objects by means of adhesive filaments.
They are relatively large (2 mm), oligoplasmic, and variably more or less
spherical to ovoid. Egg diameter is similarly variable (Parin 1958, Kotova
1958). Saury eggs take approximately four times longer to hatch than anchovy
eggs; however, newly hatched larvae are comparatively Large (6 mm), born
with functional eyes, pigmented mouth, and functional pectoral and caudal
fins (Ahlstrom 1968, Inoue and Hughes 1971) (Fig. 111.16.5; Table 111.16.1).

Growth "and Development

Growth

The early growth and development of Pacific saury has not been extensively
investigated in all subpopulations. Novikov (1973) described the early life
history of Aleutian Pacific sauries.

Newly hatched saury larvae are classified as prolarvae and preformed larvae.
Prolarvae are yolk sac, non-feeding larvae with dorsal and ventral fin folds.
Preformed larvae float and feed passively. At lengths greater than 7 mm,
they start feeding by passively ingesting food whose availability and accessi-
bility is primarily determined by the size of their mouth opening. Formed
larvae (8-20 mm) have fully absorbed their yolk sac, are swimming very ac-
tively and feed in a somewhat selective manner. Ossification of the vertebrae
and initial scale formation take place in this stage. The food quantity
and types of zooplankton ingested by saury larvae closely reflect those
present in their immediate environment. Sauries 20-50 mm long are classified
as fry, having completed their larval development at approximately 25mm
in length. Saury fry possess body pigmentation, scales, and fully developed
fins. Their feeding habits are quite selective, focusing on copepods. Fry
development completed, sauries Larger than 55 mm are juveniles and are identi-
cal to adults in both form and feeding habits.

Asian Pacific sauries grow from 60 mm to 140 mm in approximately six months.
However, North American Pacific sauries grow more slowly and are generally
smaller and leaner than their Asian counterparts of the same age. Aleutian
sauries grow the largest and heaviest (Sokolovskii 1969, Trumble 1973).

Food and Feeding

The digestive system of the saury lacks a stomach proper. It is composed
of a straight gut with valves separating it into oesophagus, intestine,
and rectum (Hotta and Odate 1956). Pacific sauries do not, at any stage
of their life cycle, forage on phytoplankton, nor are they cannibalistic.
Sauries are active predators and selective zooplankton feeders (Kasahara
1961, Trumble 1973). Larvae feed on calanoid copepods, Limacina sp., nauplii,
small mysids, zoeae, and fish eggs. Fry and juveniles feed on numerous zoo-
plankters, especially copepods, fish eggs and larvae. Adults forage on most

approximately 20 cords
(10 μ diam. each)

4.

1.32 to 2.23 mm diam.

1.

2.

A single cord 90 from the others (20μ)

Biological zero temperature = 5.5°C
(Hotta, '65)

3.

Purple-green to blue

5.

Silver-white to blue-white

1mm approx.
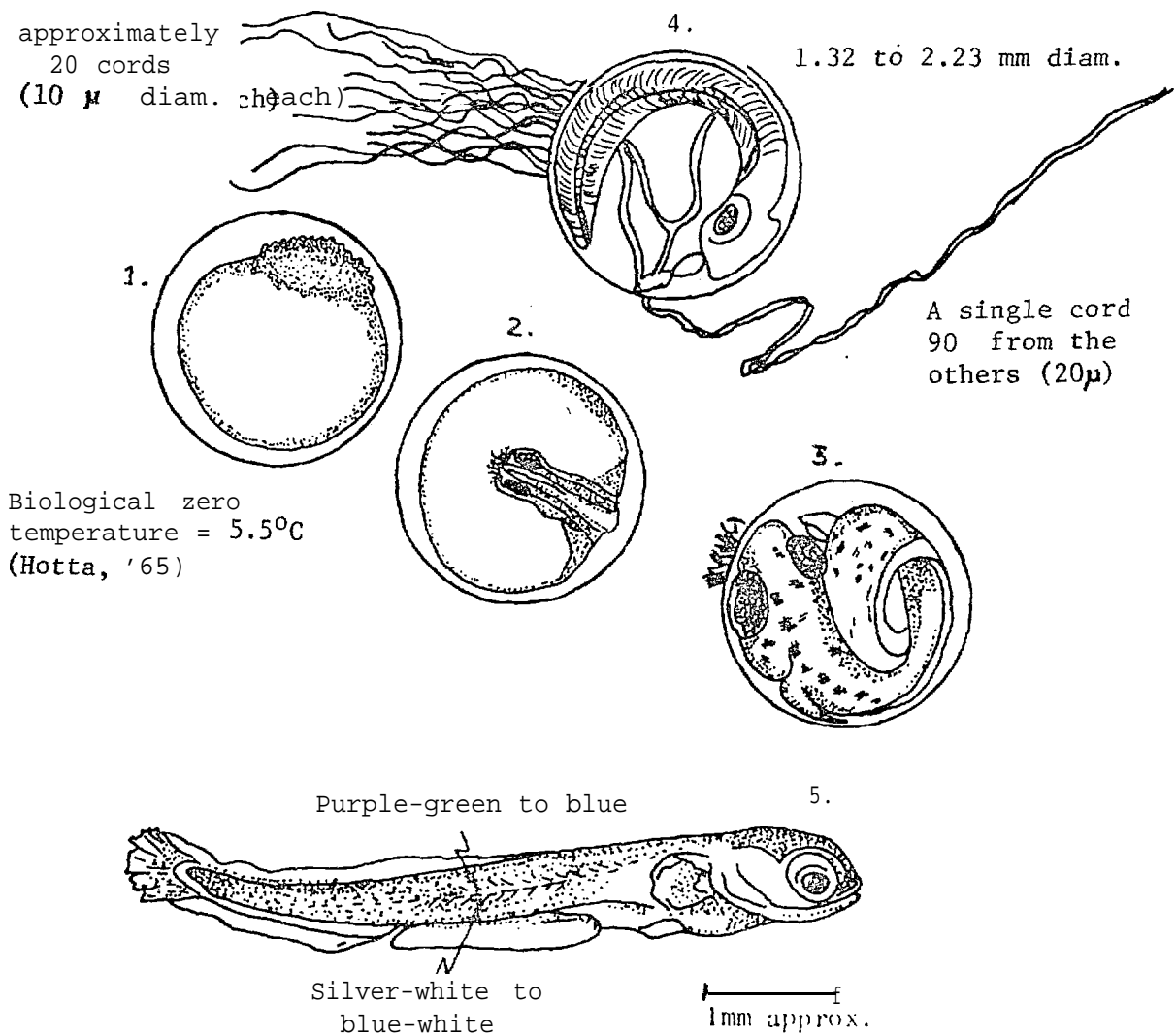
Figure 111.16,5.--Four stages of embryonic development and newly hatched larva of the Pacific saury (adapted from Hatanaka 1956 by Inoue and Hughes 1971).

Table 111.16.1.--Flow diagram summarizing the general development stages of the Pacific saury (after Japan Saury Study Group 1968, cited by Inoue and Hughes 1971).

```
┌──────────────────────────────────────────────────────────────────┐
│ ;G - 1,000 to 4,500 eggs spawned by individual females at each of 6│
│        to 7 spawnings.                                             │
│      - Eggs have a dozen cords on one end and a longer cord on the sid│
│        vertical to the longitudinal axis, which typically become entan│
│        gled in or attached to floating or fixed objects.          │
│      - Eggs are oval, 1.73 to 2.33 mm in length, 1.51 to 2.00 mm in│
│        diameter, and are typically transparent and colorless in their│
│        earlier stages, becoming green-violet in their last stage. The│
│        are slightly buoyant in seawater, having a density of 1.055.│
│      - The incubation period varies from 15 days at 15° C. to 10.5 day│
│        at 20°C.  Eggs will not develop in waters below 5.5°C.  (biolog│
│        ical zero).                                                 │
└──────────────────────────────────────────────────────────────────┘
                                    ⇓
┌──────────────────────────────────────────────────────────────────┐
│ LARVAE                                                             │
│ Pre-larval stage: 5.3 mm to 7.8 mm in length. For 3 to 4 days,     │
│        nutrient is derived from yolk.                              │
│ Post-larval stage: 8 to 25 mm in length. Fin-rays and bones reach  │
│        adult numbers.                                              │
└──────────────────────────────────────────────────────────────────┘
                                    ⇓
┌──────────────────────────────────────────────────────────────────┐
│ JUVENILE                                                           │
│      - 25 to 60 mm in length.                                      │
│      - Otoliths are formed and the first ring appears.             │
│      - Adult number of gill-rakers formed.                         │
│      - Heads are shorter than adults.                              │
│      - Swimming ability develops.                                  │
└──────────────────────────────────────────────────────────────────┘
┌──────────────────────────────────────────────────────────────────┐
│ YOUNG                                                              │
│ Youth stage: 6 to 10 au in length.  Adult in external appearance but│
│        gonads are immature.                                        │
│ Pre-adult stage: 10 - 23 cm in length (KL). Gonad weight fluctuates│
│        seasonally when size reaches 20 cm   Known to carry eggs when│
│        22 to 23 cm long.  Sexes can be identified by the gonad weight│
│        (GW) when fish measure over 10 cm in length.                │
└──────────────────────────────────────────────────────────────────┘
                                    ⇓
┌──────────────────────────────────────────────────────────────────┐
│ ADULT                                                              │
│ Food-seeking stage:  Fish feed heavily and grow rapidly, condition │
│        factor shows considerable variation between schools.        │
│ Pre-spawning dispersal stage: Saury lose weight as GW increases. Con-│
│        centration of Vitamin A is translocated to reproductive organs.│
│        Poor attraction to artificial lights noticeable in fish 28 to 3(│
│        cm long (lU).                                               │
│ Spawning stage: 29 to 30 cm in length. Mortality is high after     │
│        spawning.                                                   │
└──────────────────────────────────────────────────────────────────┘
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pelagic **crustacea**, especially **copepods, euphausiids**, amphipods, and **occasional-ly** on anchovy larvae. Copepods are predominant among preferred forage in the diet of the adult **saury**, although seasonal and area variations do occur because of variations in availability (Hotta and Odate 1956, Novikov 1966b, Miklukhina 1971). In spite of their selective feeding, the diet composition (Table 111.16.2.) commonly reflects the relative abundance and types of **zooplankton** present in the feeding area (Miklukhina 1971, Frey 1971).

Table 111.16.2.--List of organisms found in the intestines of .saury (from Mikhlukina 1971).

Protozoa
    Foraminifera
Ostracoda
    Conchoecia borealis
Copepoda
    Nauplii Copepoda
    Calanus glacialis Jaschnov
    Calanus pacificus Brodsky
    Calanus plumchrus Marukawa
    Calanus cristatus Kröyer
    Eucalanus bungii Giesbrecht
    Eucalanus subcrassus Giesbrecht
    Eucalanus crassus Giesbrecht
    Pseudocalanus elongatus Boeck
    Gaetanus simplex Brodsky
    Euchirella brevis Sars
    Euchaeta marina Prestandrea
    Scolecithrix danae Lubbock
    Metridia pacifica Brodsky
    Candacia columbia Campbell
    Candacia bipinnata Giesbrecht
    Candacia bispinosa (Claus)
Harpacticoidae
    Sapphirina stellata
Cirripedia
    Cirripedia st. cypris
Amphipoda
    Hyperridae gen. sp.
    Euprimno macropa
Euphausiacea
Mysidacea
Decapoda
    Larvae Decopoda
    Zoea larva Albinea
Appendicularia
    Oikopleura sp.

Pacific sauries feed actively throughout the year with no significant de-
crease in the feeding rate (gut fullness 60-80%) observed at any time (Kasa-
hara 1961). Their adiposity increases seasonally prior to spawning and,
additionally, adiposity increases with age (Trumble 1973). Overall, the
feeding rate is highest at the juvenile stages and, as a function of food
abundance, apparent feeding rates are higher in spring and autumn. Differences
in feeding rates beyond those dictated by season and age are not apparent.

Sauries detect their prey by visual means. They forage in the 20-30 m sub-
surface layer and their feeding all but ceases at night (Trumble 1973).

Aging and Growth Differences

Aging of sauries is currently accomplished by scale reading. However, the
method is not very accurate and there is some disagreement on the inter-
pretation. Ages determined by Soviet and Japanese investigators (Fig. III.-
16.6) often differ by as much as a whole year (Kasahara 1961; Novikov
1960, 1973; Hughes 1974).

The age of Pacific sauries is somewhat more reliably estimated when fish
longer than 30 cm are involved. Saury scales do not ordinarily reflect annual
growth patterns because sauries, having a seasonal migration to areas of
optimum food abundance and favorable temperature regimes, do not normally
experience a seasonal slowdown (Kasahara 1961). Seasonal growth rings found
on scales of older sauries have been associated with food abundance during
the spawning season (Novikov 1960).

The long spawning season and wide-ranging habit of the species has all but
precluded the use of length-frequency methods for the determination of age
composition. Hughes (1974), using age information obtained from scales and
assuming no growth difference between sp ring and fall born sauries, estimated
a growth curve: $L_t = 342.36 (1 - e^{-0.41 (1 - f - 0.72)}$ (Figs. 111.16,7., III.-
16.8; Table 111.16.3).

In the North American subpopulation, there have been no observed differences
in growth rates between years or different areas. The only apparent growth
differences are between the two sexes. Female sauries are leaner and longer
than males in the immature stage but become heavier from the onset of maturity
onward (Hughes 1974) (Fig. 111.16.9).

Growth differences are more pronounced between the various subpopulations.
Aleutian sauries are the largest of all, presumably because of the uniformity
of their environment and lower degree of competition. Asian sauries are
larger than comparably aged North American fish which must live in a less
favorable environment (Sokolovskii 1969, Hughes 1974).

Predation

Pacific sauries are preyed upon by a large variety of predators. Their speed
and elusiveness acts as a limiting factor on their predators which must
overmatch them (Grinols et al. 1968).
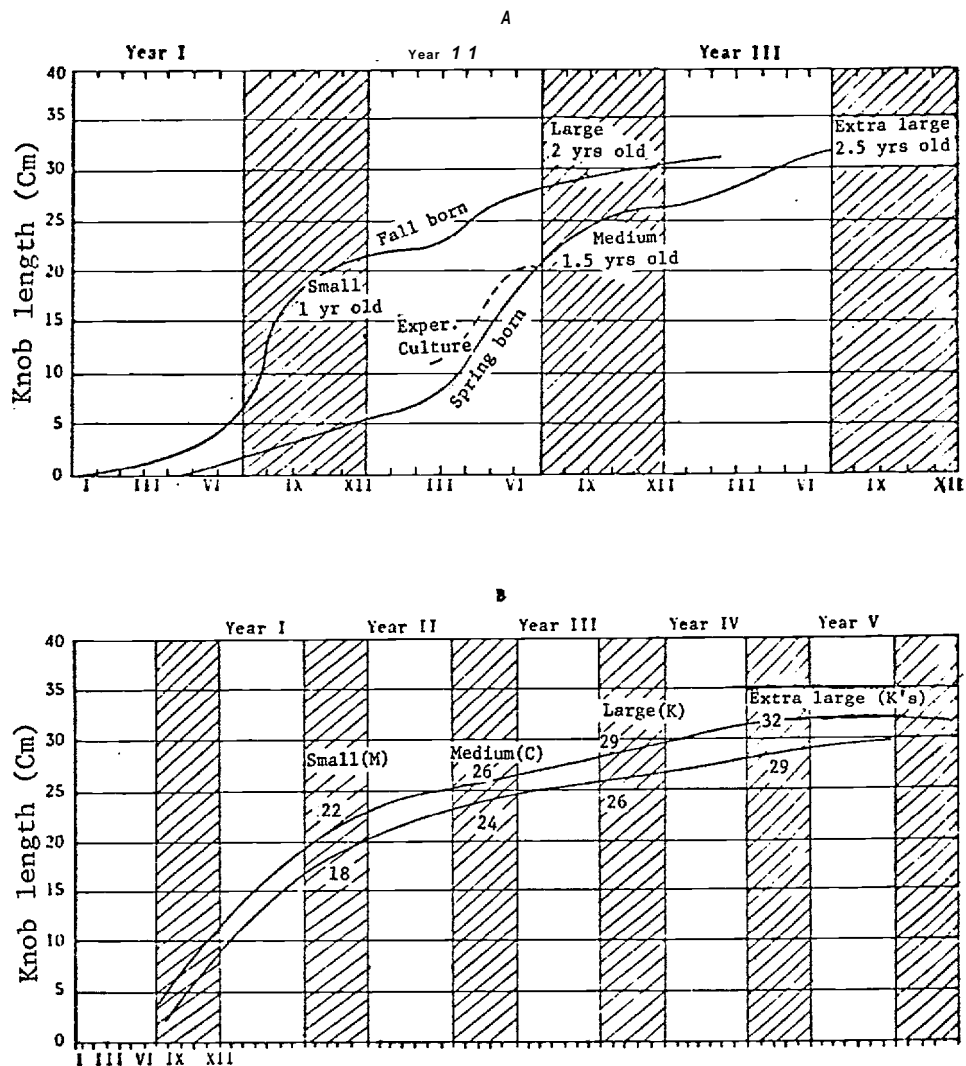
Figure III.16.6.--Growth in length of Pacific saury as interpreted by (A)
Japanese and (B) Soviet scientists* ，haded months correspond
to fishing seasons. The two lines in (B) indicate range of
growth (after Hotta 1969 and Naito 1967 unpublished manu-
script, as cited by Inoue and Hughes 1971).

Saury larvae, to a large extent, provide forage to other pelagic fish, such
as anchovies, although invertebrates, including Velella sp. have been observed
capturing them. Juveniles and adults are routinely preyed upon by skipjack.
bluefin tuna, albacore, mackerels, whales, porpoise, seals and squid (Inoue
and Hughes 1971; North Pacific Fur Seal Commission 1962, 1969, 1975; Geptner
1.976) .
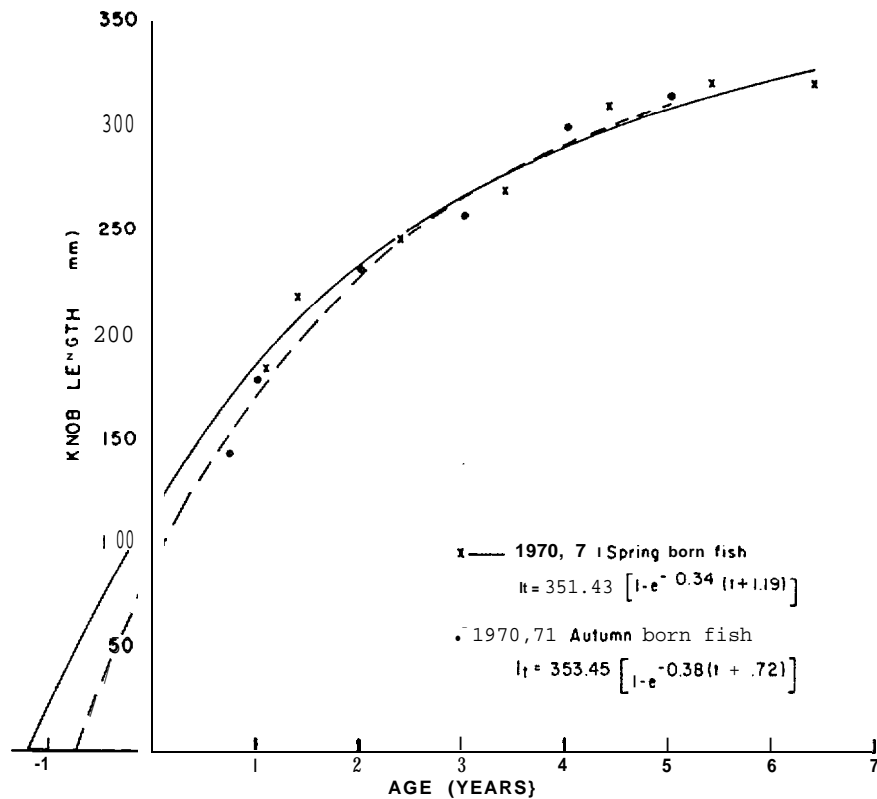
Figure III. 16.7. --Average observed lengths at age and fitted growth curves of spring- and autumn-born saury captured in offshore waters from southern California north to British Columbia 1970-71 (from Hughes 1974).

Table 111.16.3. --Average observed length at age, lengths calculated from weight at age, and estimated von Bertalanffy growth parameters of hypothesized spring- and autumn-born sauries (from Hughes 1974).

	Spring born fish			Autumn born fish	
Age [years]	Average observed length at age [mm]	Length calculated from weight at age[1] (mm)	Age (years)	Average observed length at age (mm)	Length calculated from weight at age[2] (mm)
}.10	183.9	182.5	0.75	142.8	151.2
1.40	219.0	223.6	1.00	178.7	182. 1
2.40	245.5	249.3	2.00	232.1	235.8
340	268.8	272.7	3.00	256.8	260.6
4.40	308.6	312.5	4.00	297.0	303.0
5.40	319.8	321.4	5.00	314.5	316.8
6.40	319.9	323.0			
	$L_\infty = 351.43$	$L_\infty = 360.23$		$L_\infty = 353.45$	$L_\infty = 348,50$
	$K = 0.34$	$K = 0.36$		$K = 0.38$	$K = 0.38$
	$t_0 = -1.19$	$t_0 = -0.83$		$t_0 = -0.72$	$t_0 = -1.02$

1 $W = 1.497 \times 10^{-6} L^{3.189}$
2 $W = 1.809 \times 10^{-6} L^{3.155}$
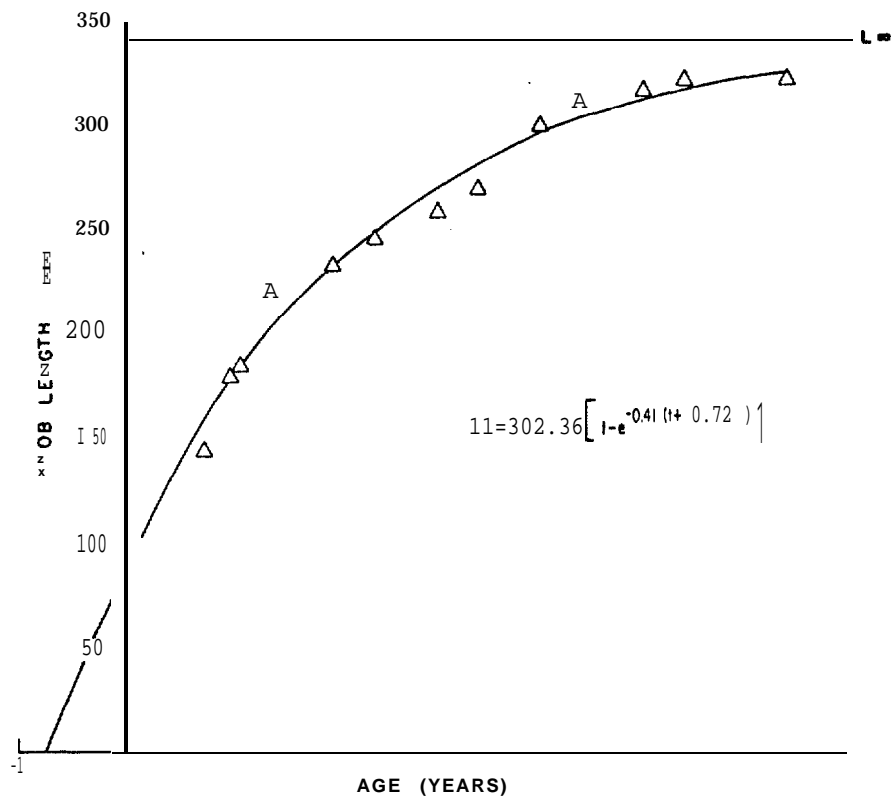
Figure 111.16.8. --Average observed length at age and fitted growth
curve of eastern Pacific saury after pooling data from spring- and
autumn-born fish (from Hughes **1974).**
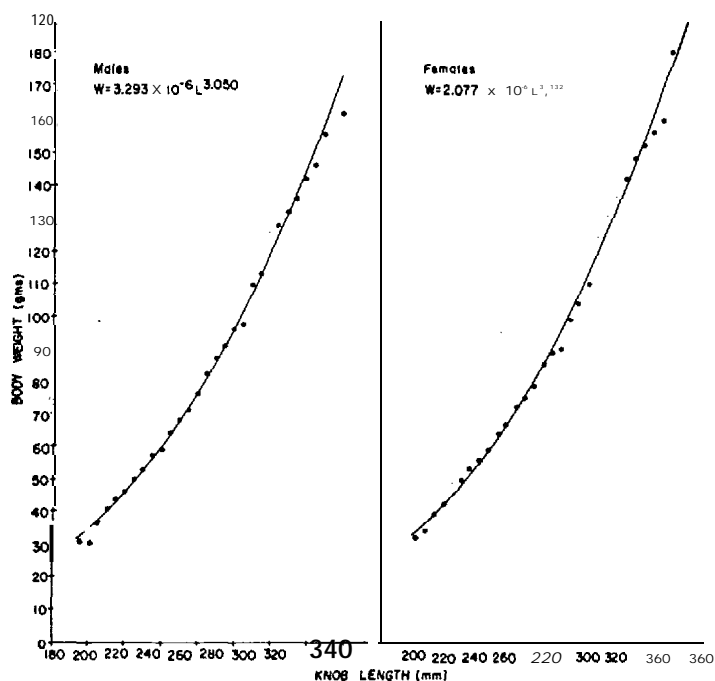
Figure 111. **16.9.--Length-weight** relation of male and **female saury.**
The curve is fitted to mean-observed weight per 5-mm length
interval (from Hughes 1974).

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Sauries rate third in importance as a food item of fur seals off California, and sei whales have been known to feed on sauries to capacity (Gill and Hughes 1971). Sei and sperm whales have been observed feeding on sauries by ingesting entire schools. Off California, albacore and marlin are apparently quite dependent on Pacific sauries which at times constitute up to 75% of their diet (Frey 1971). Other occasional predators include striped porpoise, Pacific halibut, coho salmon, sablefish, blue sharks and soupfin sharks (Inoue and Hughes 1971).

Competition

Major food competitors of sauries, primarily along the North American and Asian coasts, are anchovies, chub mackerel, jack mackerel and herring (Novikov 1971). Apparently the larval stage of the saury may be critically affected by competition whenever larvae of different species must compete for similar food items at a passively feeding stage. In this respect, the chub mackerel is reportedly the most serious competitor because the range of distribution and periods of high larval abundance of the two species quite often overlap. 'L'he food items involved are quite similar, and quite often chub mackerel larvae are favored by a relatively higher tolerance to temperature changes (Novikov 1971).

Parasites and Diseases

Pacific sauries of all populations are parasitized; however, the degree of infestation is quite variable. The North American subpopulation carries the heaviest infestation, and the Aleutian is the lightest.

Parasites have been utilized by Soviet investigators as indicators of populations and origin. There are 8 parasites peculiar to North American and Asian sauries, not found in the Aleutian stock. Further, there are 12 parasites peculiar to Asian and 2 peculiar to North American sauries alone (Sokolovskii 1969). Major parasites of the North American subpopulation include, but are not limited to, Penella sp., Calligus macarovi (absent in the Aleutian subpopulation) , and Rhadinorhynchus cololabis, as well as various nematodes (Hughes 1973).

Of all parasites, Penella appears to be the most damaging to the hosts. Infested individuals suffer extensive tissue damage and weight loss of up to 17%. Multiple infestations are quite common, and the degree and incidence of infestation apparently is independent of host size or age. Infestation by any of the above parasites, however, is quite variable among different areas and years (Hughes 1973) (Table 111.16.4).

Behavior

Not unlike the distribution, the overall behavior of Pacific saury is strongly influenced by environmental factors of which temperature is foremost. The horizontal and vertical distribution of sauries is determined by the presence of temperature gradients between currents, upwelling plumes and vertical stratification of water masses.

Table 111.16.4.--Numbers and percentage incidence of copepods (<u>Pennella</u> sp. and <u>Caligus macarovi</u>) in two possible subpopulations of eastern Pacific saury. Chi-square values are presented testing the null hypothesis that no significant difference in numbers of infections exists (0.05 level) between the hypothesized spring- and autumn-born fish. Fish ages are in parentheses (from Hughes 1974).

Year and area	Pacific saury examined for Pennella sp.	Number of saury			Incidence of infection (%)	X^2	Null hypothesis	
		Noninfected	Infected	Total			Accept	Reject
1970:								
Washington	Spring born (II)	221	47	268	17.5	1*03	x	
	Autumn born (II)	51	7	58	12.7			
	Spring born (III)	103	45	148	30.4	0.42	X	
	Autumn born (III)	63	33	96	34.4	"		
Oregon	Spring born (11)	154	64	218	29.4	6.93	–	0.01
	Autumn born (II)	86	16	102	15.7			
	Spring born (III)	23	13	36	36.1	2.70	X	
	Autumn born (III)	15	19	34	55.8			

Year and area	Pacific saury examined for Caligus macarovi	Number of saury			Incidence of infection (%)	X^2	Null hypothesis	
		Noninfected	Infected	Total			Accept	Reject
1970:								
Washington	Spring born	329	114	443	25.7	0.58	X	
	Autumn born	126	3?	163	22.7			
Oregon	Spring born	503	71	574	12.4	1.11	x	
	Autumn born	118	22	140	15.7			
1971:								
Washington	Spring born	368	32	400	8.0	3.16	X	
	Autumn born	96	15	111	13.5			
Oregon	Spring born	1,211	83	1,294	6.4	2.42	X	–
	Autumn born	150	16	166	9.6			

Sauries primarily occupy the 0-60 m layer. Further, pacific sauries actively seek and concentrate near frontal zones with sharp temperature gradients, usually varying from 10° c to 18° C (Inoue and Hughes 1971). The apparent preference for certain temperature profiles may be related primarily, however, to the high food abundance and availability typical of these regimes (Parin 1960). Regardless of the cause, the stenothermic preferences of Pacific saury and their response to different temperature regimes has been a factor reliable enough to make forecasting of runs possible. Soviet investigators have been using forecasting methods for a number of years (Kimura 1956, Novikov 1966b).

Pacific sauries display a phototaxis similar to that of chub mackerel, jack mackerel, and squid. They are easily attracted to beams of concentrated light at night, especially when actively feeding (Parin 1958, Novikov and Klyuev 1958). Light attraction by various means has long been used in the saury fisheries where sauries are attracted and "led" by sequential lights to nets (Ellis and Hughes 1971). However, the attraction of sauries to artificial lights is moderated by various factors, such as lunar phases, spawning condition and stomach fullness. For example, actively spawning sauries are not attracted to lights because of reduced Vitamin A in their photoreceptors (Novikov 1966a, Inoue and Hughes 1971). The rather strong sensitivity to illumination displayed by sauries, whose light sensitivity spans the entire spectrum, is discussed by Sidel'nikov (1966). At illumination levels of 0.01-0.1 lux, sauries start to approach light sources, they remain a long time in the light zone at levels of 150-200 lux, they remain in the bright zone a few seconds at levels of 600-800 lux, and they avoid zones of more than 800 lux.

Pacific sauries also have a negative rheotaxis and a positive electrotaxis, being easily attracted to the anode in a direct current electrical field (Ellis and Hughes 1971).

Schooling

Pacific sauries are customarily found in schools. They do not typically form dense schools, however, but rather loose aggregations of small schools over large areas. The numbers and age composition of schools are in a constant dynamic equilibrium (Kimura 1956). School aggregations are very loose during the interspawning, feeding season, and during the larval, fry and early juvenile stages. Aggregations also diminish when temperatures approach the limits of the preferred range of the saury. On the other hand, aggregations increase in size as the end of the feeding season approaches, adiposity reaches maximum, and the spawning migration begins (Novikov 1966b).

Schools of sauries display various modes of behavior determined by seasons, light conditions, maturity stage, feeding and predation. At night sauries form loose aggregations in the 5 m to 30 m layer (Kasahara 1961). Under artificial lights these aggregations coalesce into compact schools. Saury schools may be found resting near the bottom (detectable only be acoustic methods). Near the surface, schools may cruise in a coordinated manner, mill about or, when excited or frightened, may skip and leap above the surface (Inoue and Hughes 1971).

Migrations

Cololabis saira is a typically oceanic migratory species whose seasonal migratory routes lie in a roughly north-south direction. In early spring, sauries migrate northward to summer feeding grounds in widespread aggregations of small schools (Novikov 1966b , Frey 1971). The migration is reversed in late summer and autumn. In both cases, older adults tend to lead in migration, with juveniles and younger adults bringing up the rear (Inoue and Hughes 1971). In the Asian subpopulation, it has been observed, the juveniles tend to stay farther inshore during migration. Spring migration follows the spawning season, and the autumn migration precedes it (Trumble 1973).

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The migration routes are quite variable from year to year because schools apparently follow currents and fronts which are always in a dynamic state of flux. Furthermore, the timing and progress of migration are often affected by cross-route thermal fronts which act as barriers and give rise to increased concentrations of schools. Finally, the length of stay in a given feeding area is again dominated by the same temperature-related, dynamic environmental processes (Kimura 1956; Novikov 1966a, 1969; Parin 1968; Inoue and Hughes 1971).

Diurnal vertical migrations occur between the surface and the 60-70 m layer in small aggregations. The depths at which sauries are ordinarily found during the day are apparently directly related to illumination and vertical stratification (Kasahara 1961, Inoue and Hughes 1971).

POPULATION STRUCTURE

Because of the uncertainties in the methods used for the determination of the age of sauries, serious doubts exist concerning any definite description of the population structure. The concept of three geographically separated subpopulations introduced by Novikov and Chernyi (1967) and subsequently refined has been but a single step in the direction toward defining the various parameters necessary to describe local populations.

Most sampling of sauries has been conducted during their prespawning or post spawning migrations in addition to sampling on the spawning grounds themselves. Juvenile sauries tend to segregate from the main body of spawners at that time, and so they have seldom, if ever, been adequately sampled. Their age, sex, and length frequencies are not well known (Novikov 1960, Hughes 1974). Juveniles and adults are thoroughly integrated in the northern feeding areas; however, sampling has not encompassed such locations in the past. The situation has been additionally complicated in the past by the variability of migration routes and immigration factors.

A number of factors concerning the population structure of Asian and North American sauries have been deduced to date. The number of males and females is nearly equal through their third year of life; however, females predominate in fish aged 4 and 5 (Novikov 1973, Hughes 1974) (Table 111.16.5).

Table 111.16.5.--Sex ratios of age groups of saury sampled in areas off Oregon, Washington, and British Columbia, 1970-71 (from Hughes 1974).

YeOr-Ores category	Age group	Total no. fish examined	No. fish used for sex ratio	Sex ratio (% males)
1970				
Wash.	1.3	578	253	49.4
Oreg	1.3	702	143	43.4
Wash.	4.6	28	26	30.8
Oreg.	4-6	10	10	0.0
1971				
Wash.-B.C.	1-3	179	loo	54.0
Oreg.	1-3	1,365	1,024	54.1
Wash..B.C.	4.6	39 I	388	37.6
Oreg.	4.6	B	b	33.3

The overall length frequency is variable from trimodal to quadrimodal and that of the spawners varies from unimodal to bimodal. Figure 111.16.10 shows one such size composition of fall migrating saury near Japan; no definite ages have been assigned to the modes because of their variability and the previously discussed age determination difficulties. Hughes (1974) found that, among sauries of the North American subpopulation, no significant differences existed between sauries of different groups, areas, spring-born versus fall-born, or from one year to the next. Figures 111.16.7-111.16.9 show the results obtained.
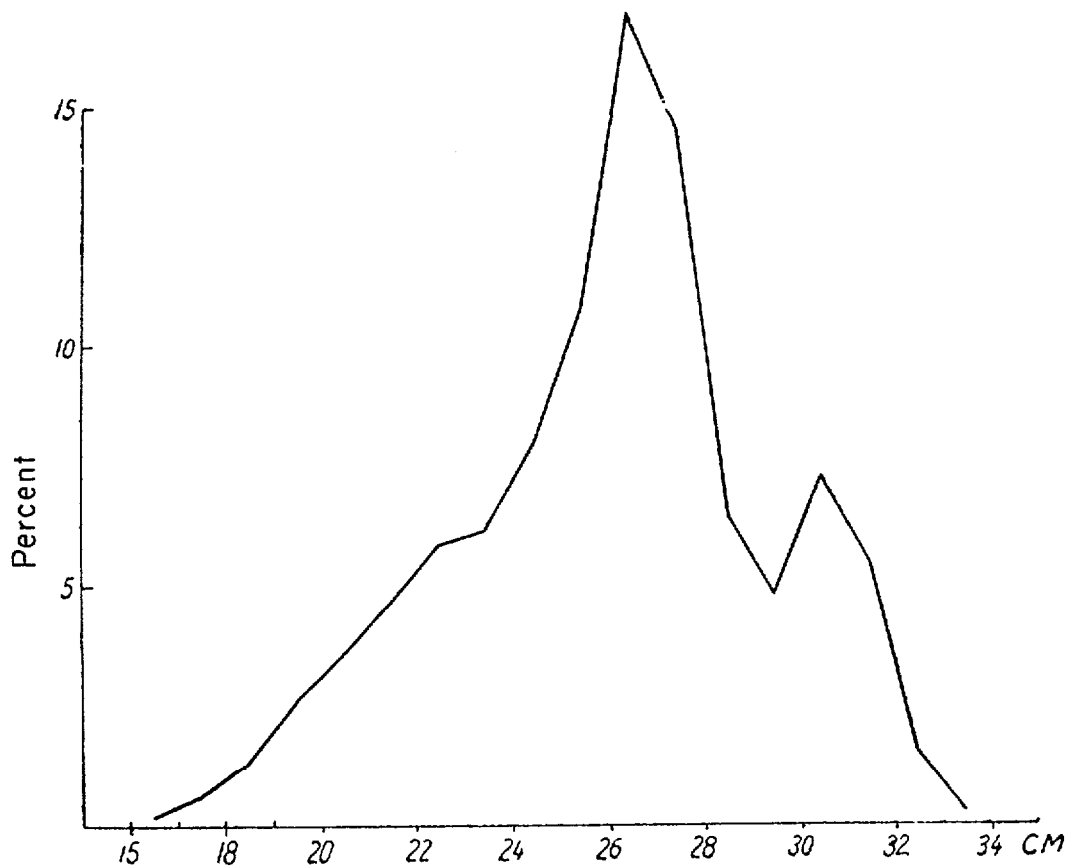
Figure III.16.10.--Size composition of Pacific saury from samples taken from commercial landings of southward-migrating schools in the Kurile-Japan area in autumn (from Novikov 1960).

Abundance

The standing stock of North American Pacific sauries is probably very large, as indicated by their importance as a food item in the diet of numerous predators. Egg and larval abundance estimates by the California Cooperative Oceanic Fisheries Investigations (CalCOFI) and visual observations coupled with predator-forage indices indicate abundance figures ranging from 450,000 to 1,500,000 metric tons, making the saury resource of the northeastern Pacific alone potentially equal to that of hake (Ahlstrom 1968, Commercial Fisheries Review 1970, Trumble 1973).

Because of the wide dispersion of schools and the lack of concentration-creating thermal fronts and sharp temperature gradients, a potential maximum sustainable yield of 100,000-200,000 metric tons has been judged to be unobtainable under present harvesting methods (Trumble 1973).

Although no information is available regarding the North American and Aleutian subpopulations, studies of the Asian subpopulation have shown that the abundance of sauries may widely fluctuate from year to year (Novikov 1969). Pacific saury subpopulations are dominated by single year classes which, in the Asian fishery, ordinarily constitute over 50% of the catch. The rapid development, high post-spawning mortality, and larval dependence on optimum temperature and forage regimes are the main causes of wide fluctuations observed in recruitment and abundance (Novikov 1969, 1971). Additionally, shifting currents, temperature changes, hardier competitors and intensive fisheries, when combined, may have devastating effects on saury populations as shown by the near collapse of the Asian subpopulation.

Pacific saury recruitment, because of the wide range of the species and the length of the spawning season, is also quite variable in space, although such variations may easily be masked by immigration and stock mixing (Kasahara 1961). In the past, recruitment has been assumed to be largely independent of spawner-recruit relations. Lack of prerecruit sampling in all subpopulations, coupled with the almost total year class replacement annually, has precluded any year class forecasting (Novikov 1966a, 1969; Serdyuk 1970}.

Saury recruitment to the Asian fishery occurs, with some fluctuation, at age 1.5 and length 24-29 cm with a mode at 25-26 cm (Novikov 1960, 1973; Hughes 1974). Age frequency statistics for the North American subpopulation have indicated probable annual variation in mortality and recruitment. Post-recruit mortality has been estimated as 69-74% (Hughes 1974).

Ecosystem Relations

Pacific sauries, along with the chub mackerel, the jack mackerel, the myctophids, and the Pacific herring, form an important link between lower trophic level crustacea and anchovies and higher trophic level fish and mammals (e.g. tunas, salmon, seals, whales, porpoises and squid). North American Pacific saury larvae are in constant competition with juveniles and larvae of chub mackerel, jack mackerel, squid and myctophids, while adult sauries provide forage for the adults of many of the above-mentioned species.

The apparent low abundance of sauries in the Gulf of Alaska and Bering Sea
is part of the overall low abundance of any epipelagic species in these
areas with the exception of salmonids.

FISHING

Although no United States fishery for sauries has materialized, sauries
have been very important to Japanese fisheries since the seventeenth century.
Fishing intensity and landings increased dramatically after 1947, following
the decline of the sardine and herring fisheries and the introduction of
new harvesting gear and techniques (Inoue and Hughes 1971, Trumble 1973).

Effort and catches in the Asian fishery peaked in 1958 with 600,000 metric
tons landed. Japanese catches, representing the greatest bulk of the landings,
decreased tenfold in the following decade (Hughes 1974). The U.S.S.R. and
Korea entered the Asian fishery in the late 1950's and early 19601s; however,
their landings have been rather stable at a fairly low level of 30,000 to
50,000 metric tons annually (Inoue and Hughes 1971, Trumble 1973) (Fig.
111.16.11).
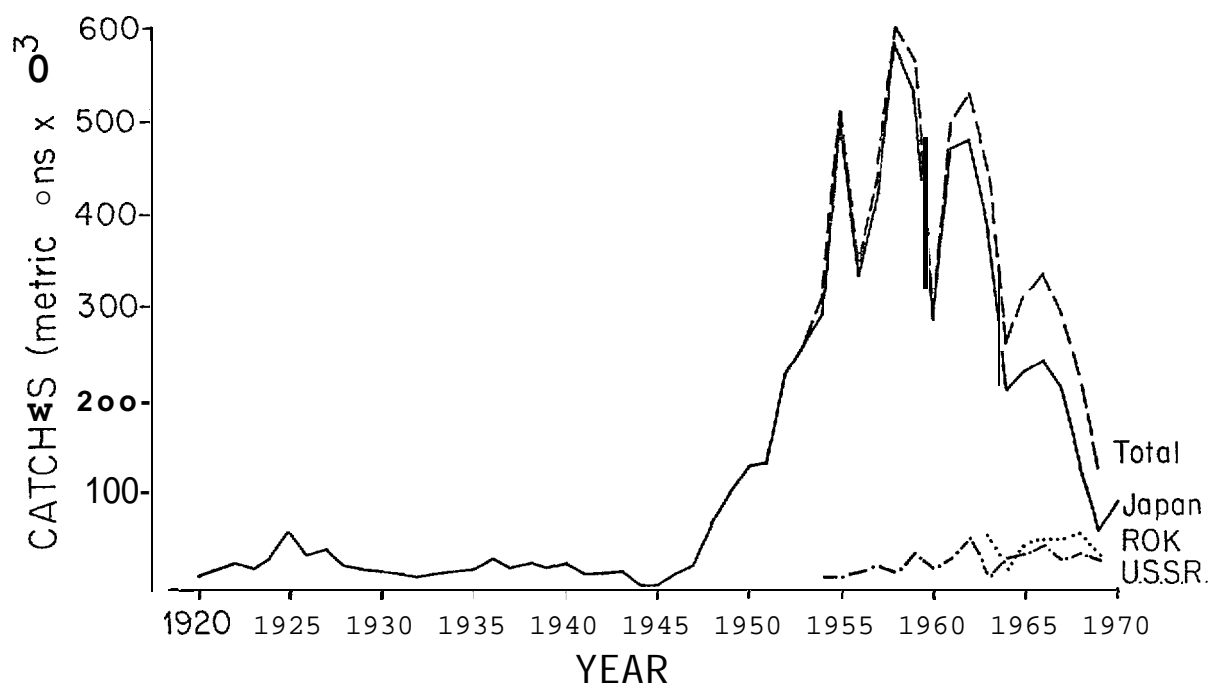
Figure 111.16.11.--Saury landings in the western Pacific Ocean (adapted
                    from Kasahara 1961; Novikov 1969, 1971; Inoue and Hughes
                    1971).

Japanese fishing companies, following the near collapse of the Asian fishery,
attempted to initiate a fishery on the North American stocks and so, after
some exploratory fishing in the late 1960's, 15 vessels in 1970 and 19 ves-
sels in 1971, conducted operations in the northeastern Pacific. No large
concentrations of saury were located, and total catches were unprofitably
low. After 1971, the venture was terminated (Trumble 1973, Hughes 1974).

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The peak fishing season for sauries in the western Pacific is from September to December during their southward spawning migration along the Kuriles and Japan (Trumble 1973).

Sauries are fished at night with the assistance of light attraction near thermal fronts with surface temperatures ranging from $13^{o}C$ to $20^{o}C$. Schools are located by visual observation on surface activity and/or bioluminescence. Additionally, echolocating and aircraft spotting have been used. Since 1947, pole-assisted liftnets (boke-ami) have been the principal gear-used, although the use of fish pumps, with lights for concentration and a DC electrical field for attraction, have been,attempted , and there also remain several coastal purse seiners and gillnetters fishing for sauries (Novikov and Klyuev 1958, 1969; Nikonorov 1964; Hughes 1974). Average nightly boke-ami catches for a vessel along the Kuriles have ranged from 3-4 metric tons to 10 metric tons (Novikov and Klyuev 1958).

Sauries are used as food fish, sold fresh, frozen or canned. They are also used as a prime bait by the Curia fisheries. In the U.S.S.R., a small portion of the catch is also reduced to fish meal (Inoue and Hughes 1971, Trumble 1973, Hughes 1974).

MANAGEMENT

Since no substantial saury fishery ever materialized in the United States or Canada, no management system has been devised, nor regulations ever imposed regarding the North American and Aleutian saury subpopulations.

In the western Pacific, early fisheries experienced constant growth with minor fluctuations in the catch even after effort was stabilized. Management measures were deemed unnecessary in view of the rising catches and employment opportunities (Kasahara 1961, Trumble 1973). In Japan, the only management instituted dealt with allocative measures restricting the length of season and attractive candlepower of large harvesting units in order to protect smaller coastal operators (Kasahara 1961). In the U.S.S.R. fisheries, a prohibition exists on fishing in the spawning grounds (Novikov 1969).

All early research was directed toward the goal of increasing the efficiency and volume of harvest. Following the near collapse of the fishery, methods have been sought to assist in the recovery of the stocks. In the U.S.S.R. , stock enhancement methods were investigated and it was discovered that straw, scattered in the sea on the spawning grounds, was utilized by sauries as spawning substrate and that up to 8,000 eggs were attached per 500 g of hay (Ayushin et al. 1967).

FUTURE OUTLOOK

Pacific sauries, currently unexploited in the northeastern Pacific, have a substantial potential for inclusion in the foodfish list. Further, they are quite valuable even when used as bait in the tuna and, potentially, other fisheries. Smaller sauries could well be utilized by the pet food industry. It is assumed that the North American subpopulation cannot support a fishery for reduction purposes.

A fishery utilizing this resource could only be successful, however, if harvesters were able to regularly locate large concentrations of schools. The association of schools with thermal fronts could be routinely used to predict probable areas of concentration through. surface temperature monitoring. Aircraft spotting at night could also be of assistance.

Sauries, like most epipelagic fish, are especially susceptible to surface pollutants whenever they enter estuaries and on the spawning grounds where surface-active pollutants can be especially detrimental to their pelagic adhesive eggs.

JACK MACKEREL (Trachurus symmetricus (Ayres) 1855)
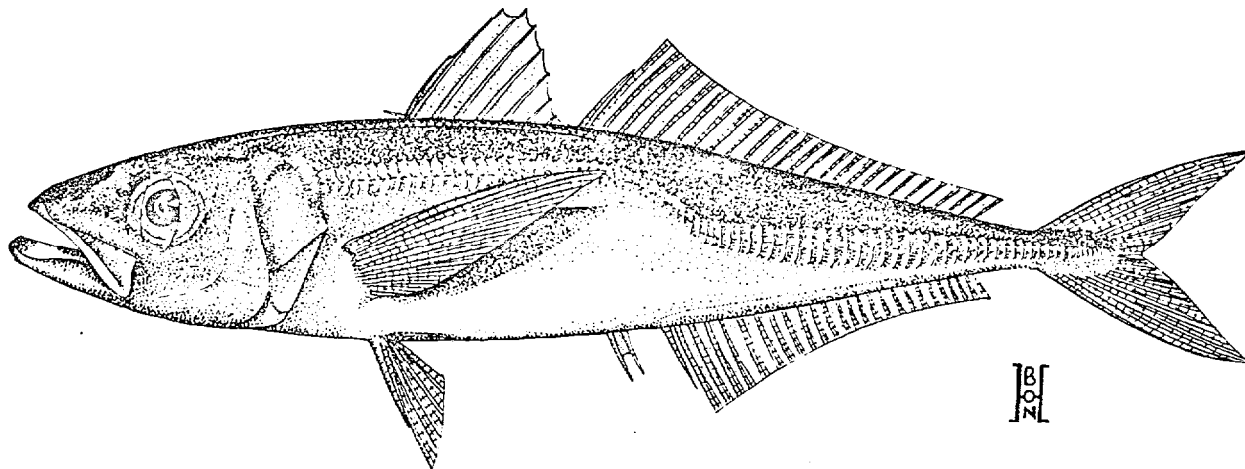
Figure 111.17.1.--Jack mackerel, Trachurus symmetricus
(from Hart 1973).

IDENTIFICATION

As with other widely distributed species, the jack mackerel has gone through
a period of identification and systematic controversies, Along the west
coast of North America it has been identified as Decapterus polyaspis by
Walford and Meyers (1944) , and it has been commonly confused with the Mexican
shad (Decapterus hypodus) and even chub mackerel (Scomber japonicus) (Larkins
1964) .

The currently accepted common name jack mackerel is a commercial one, coined
in 1947 and first used by Roedel (1948). However, a variety of other common
names have been applied:

      U.S. and Canada: scad (Clemens and Wilby 1946)
                        mackereljack (Clemens and Wilby 1961)
                        Spanish mackerel, agii, jackfish (Walford 1937)
        U.S.S.R.:   stavrida, stavridka, skumbreika, karides (Berg et al.
                          1949)

Additionally, the generic common names saurel and horsemackerel are widely
used.

Trachurus symmetricus is the only member of the family Carangidae found
in the eastern half of the Pacific Ocean north of Punta Santa Eugenia in
Baja California. Decapterus polyaspis , once thought to be a separate, northern
species, was found to be synonymous (actually, older individuals of Trachurus)
according to Roedel (1953).

The separate identity of Trachurus was officially established in 1927 when
it was separated from Scomber in the California commercial landing statistics
(Fitch 1956a).

DISTRIBUTION

Members of the genus Trachurus occur in all temperate and subtropical areas
of the Atlantic, Pacific, and Indian oceans and their peripheral seas. In
the northeastern Pacific, the distribution of Trachurus symmetricus, because
of its wide range, has been delimited gradually over a fairly long period
(Fig. 111.17.2). According to Ahlstrom (1968) , sampling for eggs and larvae
as far as 1,100 miles offshore failed to reach the limits of their range
although no eggs or larvae have been found in the central North Pacific
(Fig. 111.17.3). Adults have been caught as far north as lat 57°30'N in
the Gulf of Alaska, but the westernmost records do not extend beyond long
162W (Ahlstrom 1968, Blunt 1969) (Fig. 111.17.2).
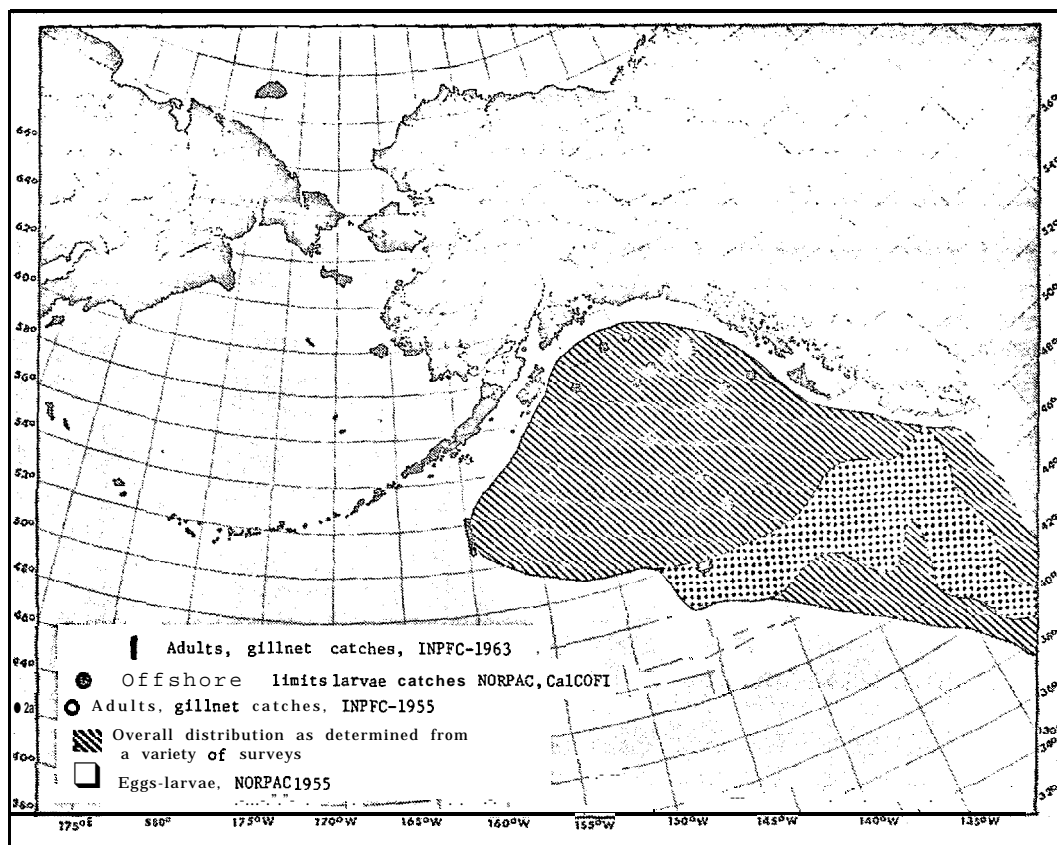
Figure 111.17.2.--Generalized pattern depicting the range of jack
   mackerel in the northeast Pacific. This range represents the
   surface distribution resulting from records of adults, juveniles,
   and eggs and larvae obtained by various Pacific coast research
   agencies (from Blunt 1969).
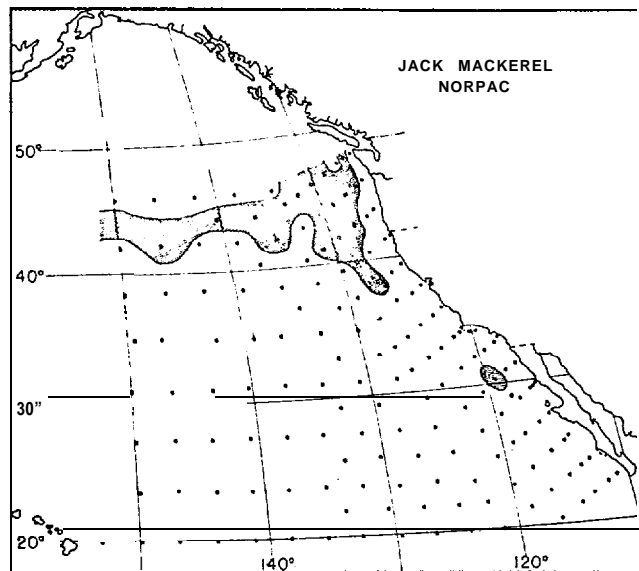
Figure 111.17.3 .--Distribution of jack mackerel eggs and larvae,
   NORPAC project (from Ahlstrom 1956).

Although the biological range of the species far exceeds the commercial,
it is widely assumed that the ranges of distribution of adults, juveniles,
and larvae are comparable (Ahlstrom and Ball 1954, Fitch 1956a).

The most intensive egg and larval surveys by CalCOFI have shown a maximum
abundance of eggs and larvae between 80 and 240 miles off southern and Baja
California (Ahlstrom and Ball 1954; Ahlstrom 1956, 1968; Kramer and Smith
1970a)(Fig. 111.17.4). The southern limits of distribution appear to be
near central Baja California (Punta Santa Eugenia), and there is some evidence
that the offshore range narrows to 500 miles off Baja California (Blunt
1969) .

The northern extension of the range into the Gulf of Alaska appears to be
seasonal in nature, and its patterns appear to conform with the general
pattern of upper layer isotherms (Fig. 111.17.5). Jack mackerel, along with
other warm water species, follow the 11°C isotherm, as summer progresses,
entering the Gulf from its southeastern areas and spreading northward and
westward (Neave and Hanavan 1960).

In contrast to the Gulf, no jack mackerel have been recorded from the Bering
Sea.

Since no fishery has been conducted and no substantial amount of research
has ever been devoted to jack mackerel in the Alaska area, a substantial
amount of information presented here comes from areas further south. It
is included in order to present a more complete summary of existing know-
ledge pertaining to the species.

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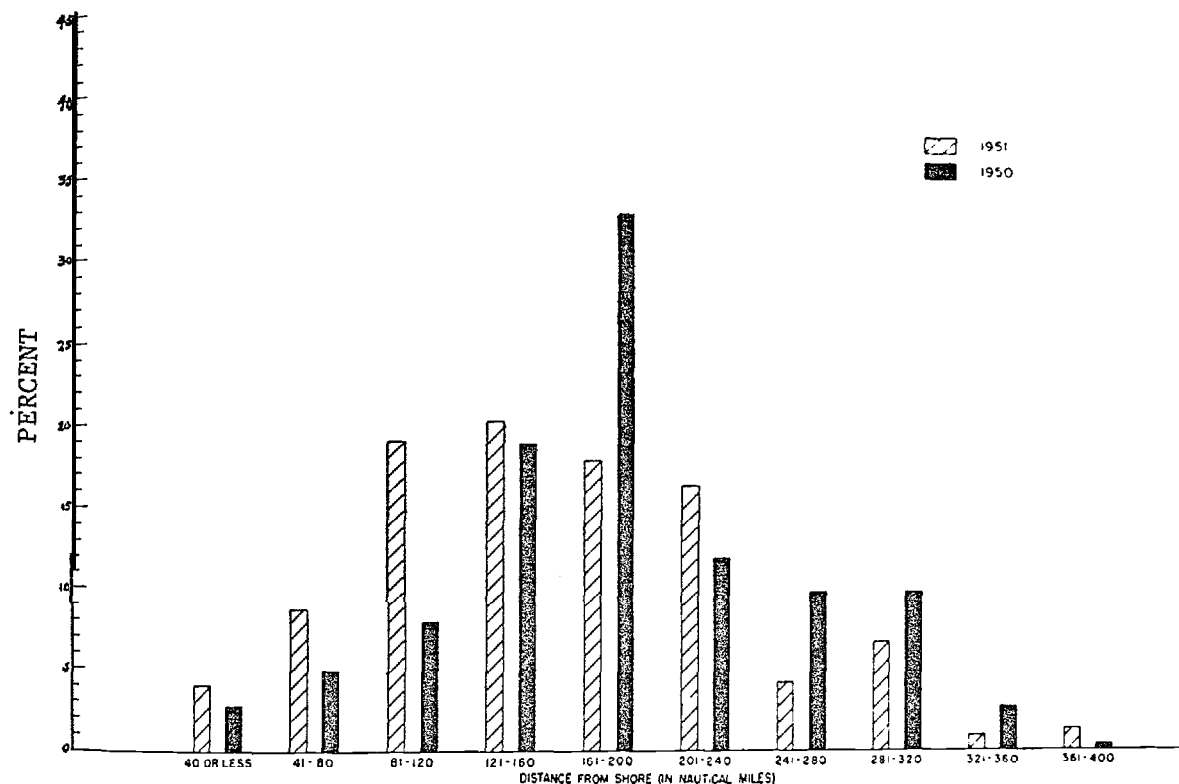
Figure 111.17.4.--The relative abundance of jack mackerel larvae in relation to distance from shore, grouped by 40-mile intervals (from Ahlstrom and Ball 1954).

LIFE HISTORY

Reproduction

Meager age and growth data suggest that 50% of the 2+ aged females (25 cm fork length) and all 3-year olds (35 cm fork length) are mature (Fitch 1956a). Information concerning the fecundity of jack mackerel is, at best, scanty; a single female, first-time spawner was described by MacGregor (1966). The fish was 21.5 cm long (standard length) and weighed 171 g. The gonads weighed 6.14 g and contained, in addition to numerous very small unyolked eggs, 52,000 to 53,000 yolked eggs in each of two size modes of 0.20-0.38 mm and 0.40-0.58 mm diameter. Bimodal egg distribution and multiple spawnings are common among pelagic fishes, but it has not been definitely established whether jack mackerel indeed undergo multiple spawnings.

Ahlstrom (1968), assuming normal egg and spawner maturation and multiple spawning as suggested by Fitch (1956a), calculated the fecundity to be 306 eggs per spawner-gram per batch. An interval of 30 days between successive maturation of the batches has been assumed. Nothing is known concerning the size and number of batches for older fish.

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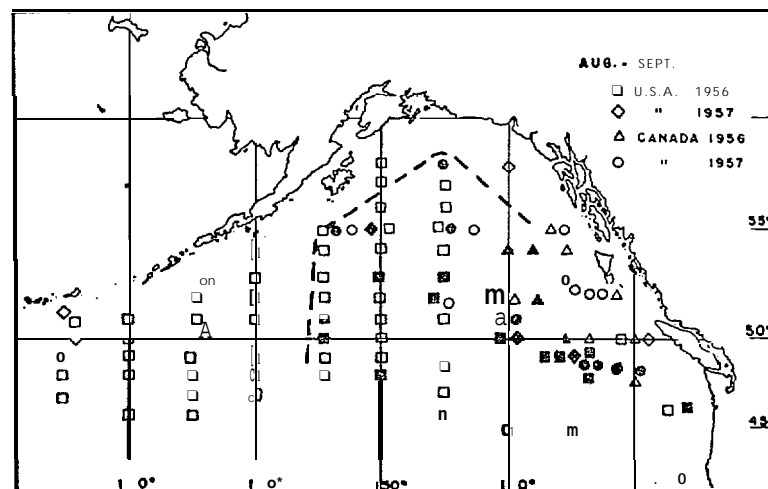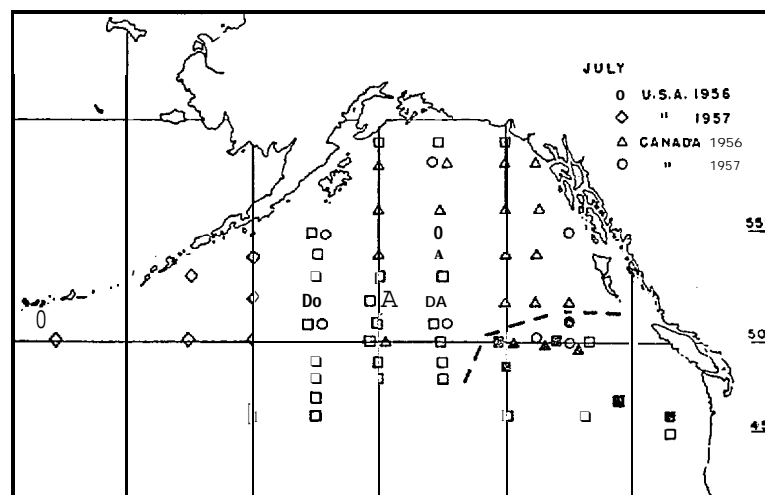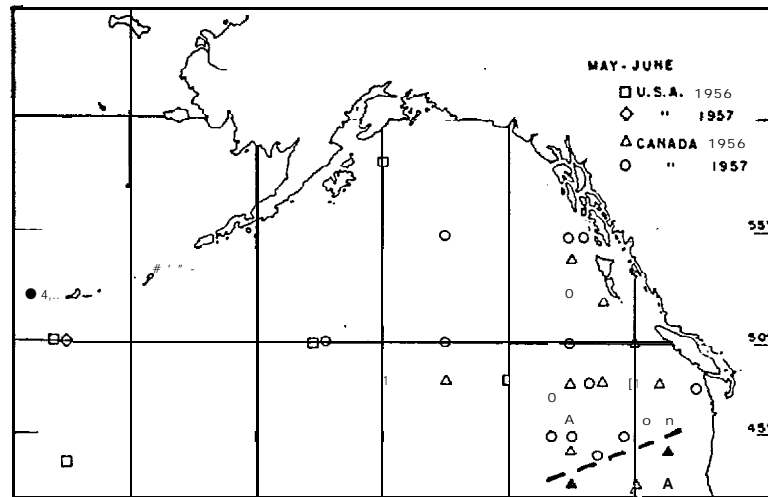
Figure 111.17.5 .--Distribution of jack mackerel in gillnet
catches in the Gulf of Alaska. The broken line represents
the approximate northern limit of catch records. (Black
symbols - occurrences; open symbols - jack mackerel not
taken.) (From Neave and Hanavan 1960.)

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Jack mackerel are pelagic, offshore spawners whose spawning season is similar to that of the sardine. According to Farris (1958), jack mackerel spawn from January to October. Early in the season, the largest numbers of spawners are found off Baja and southern California. As the season progresses, spawners are found farther north to San Francisco (Kramer and Smith 1970a), and eventually to Oregon and Washington where spawning concentrations can be found through September (Ahlstrom 1956). Off California, according to Ahlstrom and Ball (1954), the peak spawning period occurs from March to July (98% of all larvae occur at that time). Offshore spawning extends to long 150°W.

Jack mackerel spawn in the upper mixed layer, well below the surface in depths of 25 to 50 m (Ahlstrom 1956, Farris 1961). Peak spawning takes place at night in water between 10° and 19°C with optimum spawning temperatures between 14° and 16°C. The spawning time and location apparently is determined by the prevailing temperature regime, thus spawners are found farther inshore in years of diminished upwelling and higher surface temperatures (Ahlstrom and Ball 1954).

Jack mackerel eggs are pelagic, spherical, averaging 0.98 mm in diameter, nonadhesive, colorless, smooth shelled, and translucent, with segmented yolk mass which encloses a single large oil globule. The oil globule is located, in the embryonic stage, in the anterior area of the yolk (Fig. 111.17.6). This is an unusual and distinctive placement of the oil globule, peculiar to carangid fishes (Ahlstrom 1956). Jack mackerel eggs are found primarily in the upper mixed layer and very seldom deeper than 90 m. Incubation is complete in approximately 4 days at 14.3°C and in 2 days at 17.9°C (Ahlstrom 1956). According to Ahlstrom (1968), egg survival is as low as 0.1% at a mean temperature of 15.5°C.

Jack mackerel larvae hatch at a relatively undeveloped stage, much like other pelagic fishes (sardine, hake, chub mackerel). They lack a functional mouth, eye pigmentation, as well as formed pectoral and caudal fins (Fig. 111.17.7). Their low stage of development and their high mortality during the embryonic and pre-larval stages is apparently fully compensated by their high fecundity. Newly hatched larvae measure 2.0 to 2.4 mm and develop rapidly; within 2 to 3 days yolk absorption is complete. Most larvae measuring 3.3 mm have fully completed their yolk larva stage and posess a functional mouth, pigmented eyes and functional pectorals (Ahlstrom and Ball 1954).

The larvae stay and feed above the thermocline; according to Ahlstrom (1956), 80% are found in the upper 50 m and over 50% in the interval between 24 and 48 m. Jack mackerel larvae possess a disproportionately large mouth which provides an advantage in the competition for food with sardine and anchovy larvae.
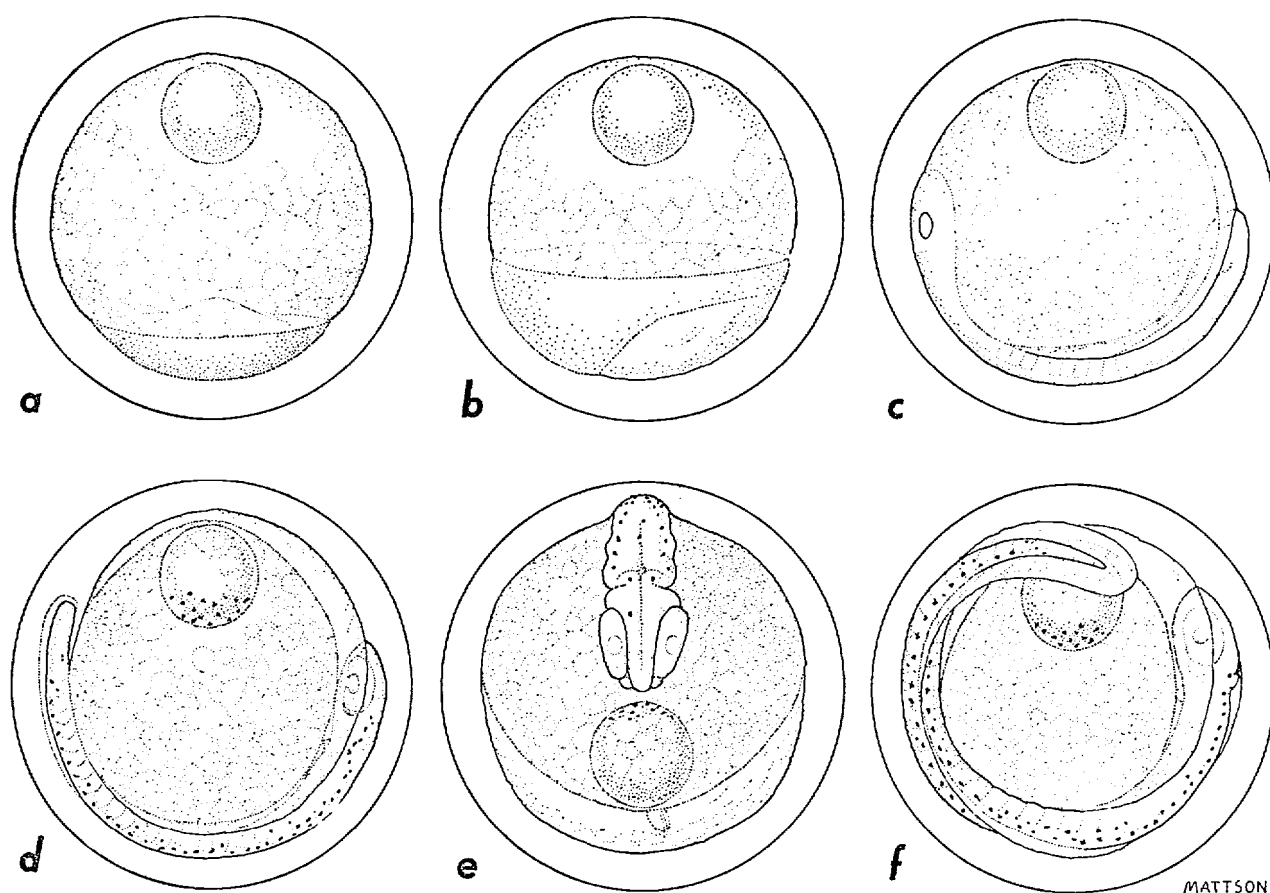
Figure 111.17.6.--Jack mackerel eggs in various stages of development.
a, b, and c - early embryonic period, c being the stage immediately
preceding blastopore closure; d - intermediate period of embryonic
development; e, f - late-period eggs with advanced embryos. e shows
an egg as viewed from above; all other figures are lateral views
(from Ahlstrom and Ball 1954).

Growth and Nutrition

Jack mackerel were first studied in California. Their age is adequately
determined from their otoliths (Roedel 1953). Information on growth beyond
the larval stage is scanty, but there is apparently no well defined larva-to-
juvenile metamorphosis (Ahlstrom and Ball 1954) (Fig. 111.17.8). As previously
mentioned, females aged 2-1- average 25 cm and those aged 3+ average 35 cm
(fork length). Length and weight data are also meager. MacGregor (1966)
places the weight limit at 2,300 g and Lmax at 76 cm. Sport catches of fish
near 75 cm long have routinely been aged from otoliths to 30 years of age
(Fitch 1956 a).

On the basis of the above, Trumble (1973) calculated, for a von Bertalanffy
growth curve, Lmax = 760 mm and $K = 0.21$ (Fig. 111.17.9). The values obtained
were in fair agreement with values observed in California landings.

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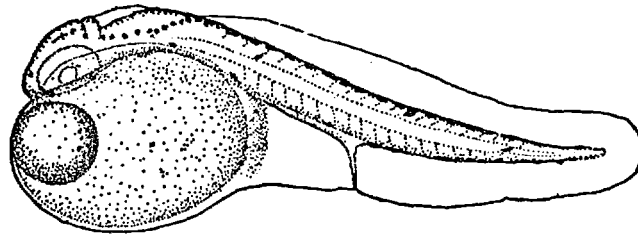
Yolk-sac larva, 2 mm. Soon **after hatching.**
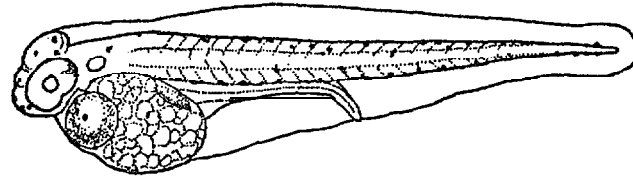
Yolk-sac larva, 2.8 mm.
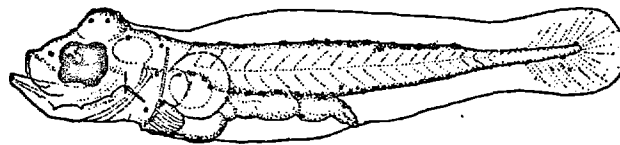
Larva, 3.5 mm.
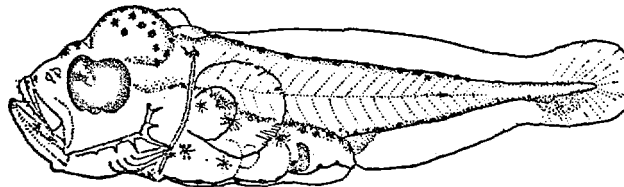
Larva, 4.9 mm., lateral view.
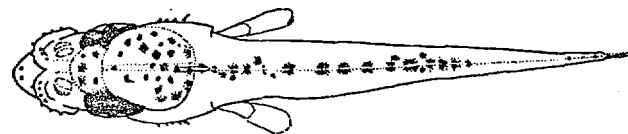
Same specimen , dorsal view.
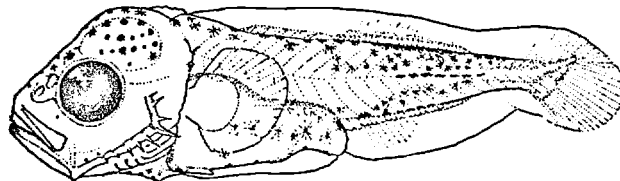
Larva, 7.4 mm.

Figure 111.17.7.--Development of jack mackerel from yolk-sac larvae to a larva 7.4 mm in length (from Ahlstrom and Ball 1954).

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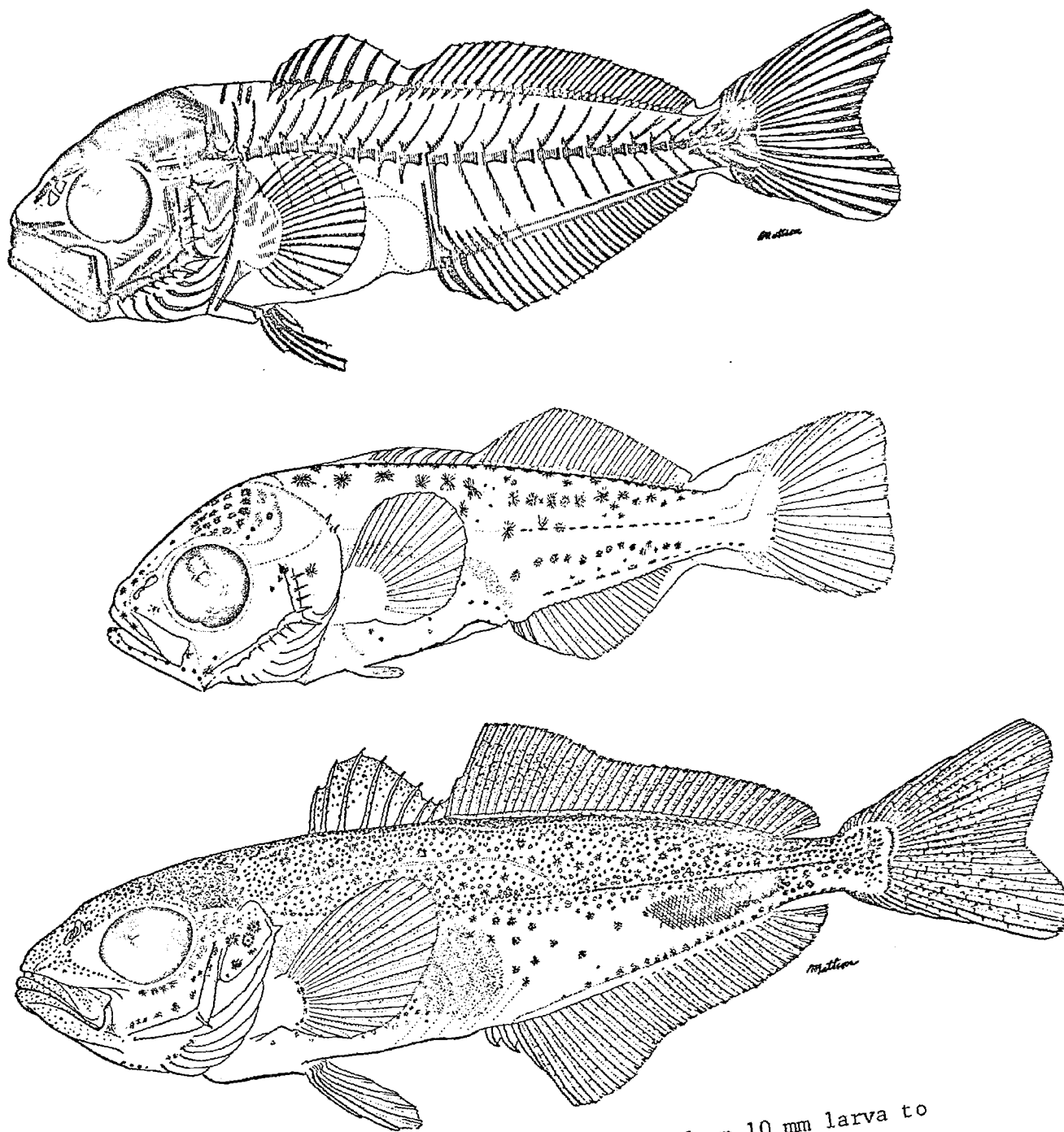
Figure III.17.8.—Development of jack mackerel from 10 mm larva to 28 mm juvenile (from Ahlstrom and Ball 1954).

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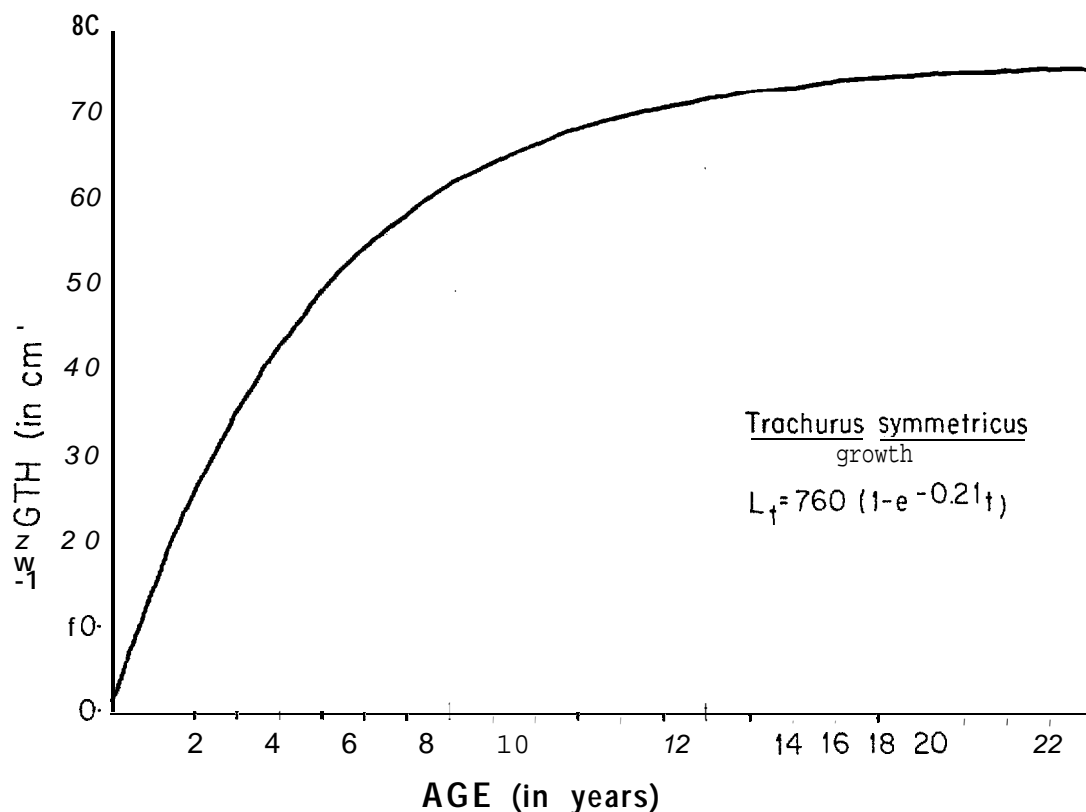
Figure 111.17.9. --Growth rate of jack mackerel from fitting
von Bertalanffy growth curve to data in Trumble (1973).

Jack mackerel is a selective predator. Larvae feed mostly on minute zoo-
plankton while the juveniles become more selective and feed mostly on cosmo-
politan species of copepods, euphausiids, and pteropods which together
constitute up to 90% of their diet. According to Carlisle (1971), euphausiids
make up 70% of the organic content of the diet and up to 1/3 by numbers.
Adults feed on zooplankton and at times they forage, quite intensively,
on anchovies, juvenile squid, and myctophids, selectively pursuing individual
prey (Fitch 1956a) (Table 111.17.1).

Predation and Competition

Major predators on jack mackerel off California include sea lions, seals,
some porpoises, yellowtail, white and giant seabasses, and blue shark. Further,
juveniles are preyed upon by albacore (Frey 1971). Jack mackerel feature
prominently in the diet of fur seals (North Pacific Fur Seal Commission
1962).

Roedel (1953) suggested that decreased competition from sardine and chub
mackerel may have been the factor responsible for the recent growth in abun-
dance of jack mackerel. However, sardine competition has been very limited
(Carlisle 1971) and, furthermore, the niche occupied by sardines has been
apparently taken over by anchovies. Chub mackerel, on the other hand, are
quite often found schooling with jack mackerel (MacGregor 1966) and, because
of their similar feeding habits, any increase in jack mackerel abundance
has probably taken place at the expense of chub mackerel.

Table III.17.1.--Plankton food items from stomachs of jack mackerel obtained off the coasts of southern" and Baja California compared with the composition of plankton samples at localities of capture (from Carlisle 1971).

	Total number taken in all stomachs	Number-of stomachs containing items	Average number per stomach containing food	Percentage of total food items by number	Percentage of plankton sample containing item
Crustacean					
Copepoda	2,240	7	29.1	33.4	100
Euphausiacea	1,803	15	23.4	26.9	38
Amphipoda	215	14	2.8	3.2	25
Decapoda larvae	66	14	0.9	1.0	93
Isopoda	31	2	0.4	0.5	4
Ostracoda	15	3	0.2	0.2	8
Cladocera	4	2	0.1	0.1	54
Cumacea	3	1	<0.1	<0.1	10
Stomatopoda larvae	1	1	<0.1	<0.1	2
Mysidacea	--	--	--	--	40
Mollusca					
Pteropoda	2,005	11	26	29.9	94
Scaphopoda	7	1	0.1	0.1	--
Squid larvae	1	1	<0.1	<0.1	--
Post-larval Lamellebranchiata	1		<0.1	<0.1	40
Protozoa					
Foraminifera	78		1.0	1.2	56
Diatoms	2		0.1	<0.1	88
Tintinnids	4		<0.1	0.1	4
Other					
Fish larvae	187	5	2.4	2.8	38
Annelida larvae	33	2	0.4	0.5	60
Invertebrate eggs	11	1	0.1	0.2	4

* 77 of 150 stomachs analyzed contained food.

Behavior

Jack mackerel school near the surface, deep enough not to show surface traces. Schooling may occur with sardines or chub mackerel as well as separately. Their schools are intermediate in compactness and organization not unlike anchovy schools, with fairly constant school size and composition (van Olst and Hunter 1970). In laboratory experiments, Hunter and Zweifel (1971) have shown that school density decreases with decreasing illumination and that the fish disperse in total darkness. Jack mackerel are able to maintain schools near the surface on starlit nights and are able to forage successfully on moonlit nights. The dominant factor involved in the formation and maintenance of schools, as well as effective selective feeding, is vision. Hunter and Zweifel found that, for jack mackerel, peak photoreception occurs at 495 $m\mu$. Jack mackerel can be attracted at night by artificial lights, and on such occasions they school 3-5 m below the surface, at the periphery of the zone of light, making predatory forays on myctophids, anchovies, and sauries gathered under the lights (Grinols and Gill 1968, Blunt 1969). In these circumstances, they display a somewhat opportunistic mode of feeding without preference among the various species of prey.

Hunter (1971) has found that jack mackerel possess special physiological and structural adaptations that permit swimming at high speeds for periods of hours and, in this respect, they are similar to scombroid fishes. Their speed and endurance provides them with a definite advantage when undertaking long migrations or when foraging on fast swimming species such as sauries.

Juvenile jack mackerel stay inshore (0-50 mi) for the first 3-6 years of their life, gradually moving deeper and farther offshore (Roedel 1953, Blunt 1969). Large adults have been taken offshore as deep as 400 m (Hart 1973).

Adult jack mackerel undertake seasonal migrations to the north and west of their winter range, into the Gulf of Alaska, following the 11°–$17^\circ C$ surface isotherms from British Columbia and southeastern Alaska, expanding their range by 1.3-2.0 million km^2 to cover the entire Gulf (Neave and Hanavan 1960). Neave and Hanavan , in considering the distances travelled by jack mackerel (over 1,500 km in a straight line) , calculated probable average migration speeds of 15-17 km/day. Blunt (1969) suggested even higher speeds of 24-25 km/day.

POPULATION STRUCTURE AND DYNAMICS

At present, no reliable information exists on the size, age, and sex composition of the northeast Pacific stock of jack mackerel.

Abundance and Density

The total, as well as regional, abundance is also a subject open to speculation. Incidental gillnet catches in the Gulf of Alaska during the summer months, have shown jack mackerel to be very abundant when compared to other pelagic species (Larkins 1964). Since the majority of the biomass off California is concentrated between 80 and 240 miles offshore and well beyond the limits of the present fishery, very little information exists on the dynamics of the population as a whole. Blunt (1969) has observed that dominant year classes are commonly evident in the fishery and that some may influence the catches for periods of up to four years. Recruitment into the California fishery occurs at age 1+.

Ahlstrom (1968) used egg data collected during CalCOFI surveys to estimate the total biomass of the spawning population. The assumptions about multiple spawnings (2-3½ per season) and fecundity increased the conservative aspect of the estimate. Nevertheless, by extrapolating the estimate to the entire range of jack mackerel, the northeastern Pacific spawning biomass was estimated to be between 2.1 and 4.8 million metric tons.

Mortality

Information on the natural mortality of jack mackerel is very limited. As stated previously, egg survival is no more than 0.1% (Ahlstrom 1968). There appears to be no especially critical period in the larval phase, although survival apparently increases following the formation of fins (Farris 1961, MacGregor 1966). According to Trumble (1973), no information is available on the natural mortality of juveniles and adults.

In spite of the wide range of the species, the U.S. fishery for jack mackerel (over 80% in California) is confined to the inshore areas, using primarily purse seines.

Jack mackerel became commercially important to the California industry in 1947 (Fig. 111.17.10). This was the result of diminished catches of sardine and chub mackerel, combined with the availability of unemployed vessels and fishermen. The resulting present-day jack mackerel fishery is not unique but rather an extension of the sardine and chub mackerel purse seine fisheries, requiring no changes in gear and only slight modifications in technique. The use of echosounding equipment greatly enhanced the fishery because jack mackerel schools do not ordinarily show surface traces. The continued low abundance of the primary target species has effectively precluded any modernization or expansion of the aging fleet and manpower.
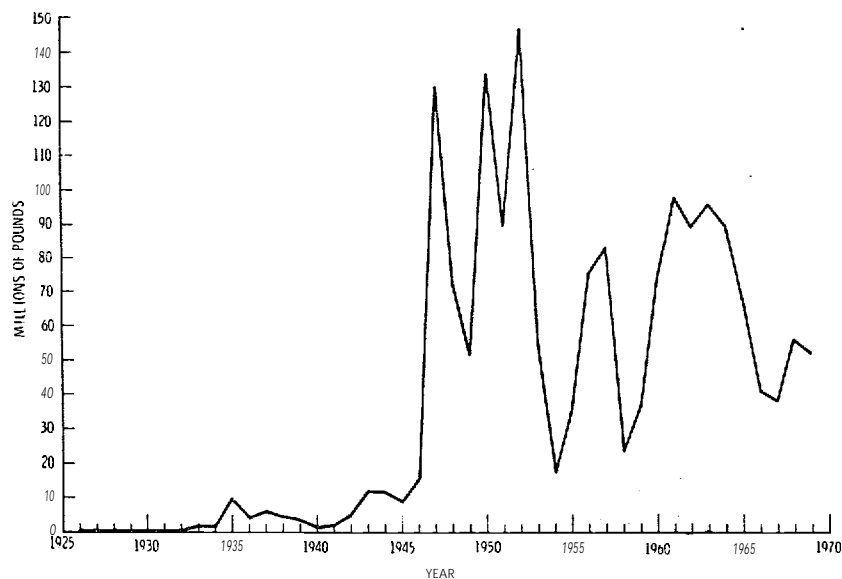
Figure III.17.10.--California commercial landings of jack mackerel (from Frey 1971).

The California fishery operates on inshore juveniles (1-3 years old, 15-38 cm). Older individuals, measuring up to 50-60 cm and inhabiting the deeper layers farther offshore, are available to midwater trawls, longlines, and to a sometimes substantial sport fishery (Roedel 1953).

The fishing season off southern Califonia spans the entire year. Farther north, and more recently, Polish trawlers have located substantial concentrations of jack mackerel (0.3 metric tons/trawling hour) off Oregon and Washington in the summer and fall (Morski Instytut Rybacki w Gdyni 1976).

No fishery has taken place in the Gulf of Alaska, and so estimates of seasonal abundance are open to speculation.
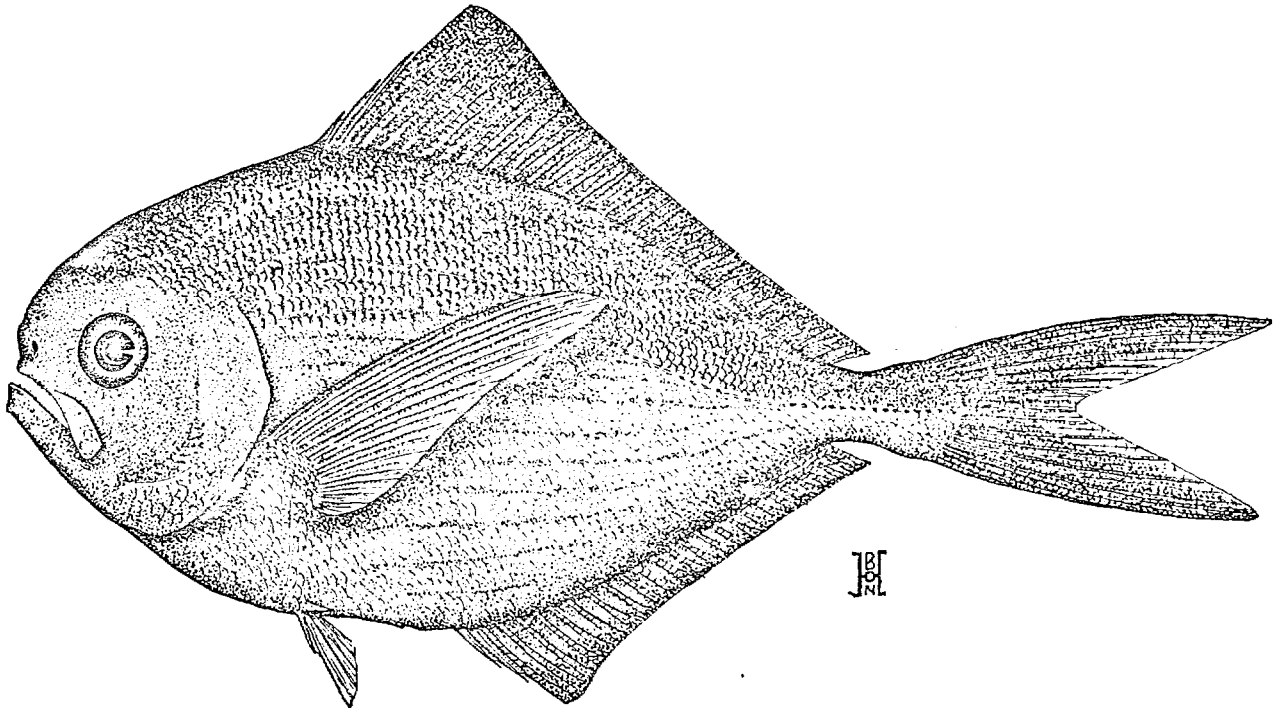
Figure 111.18. 1.--Pomfret, <u>Brama japonica</u> Hilgendorf 1878 (from Hart 1973).

As the systematic of the family Bramidae (of which the pomfret is a member) are as yet uncertain, the scientific nomenclature is confused (Hitz and French 1965). Accordingly, a series of scientific tames have been applied to this fish (adapted from Grinols 1965):

> <u>Sparus brama</u>, Bloch 1791
> <u>Brama japonica</u>, Hilgendorf 1878
> <u>Brama raii</u> (Bloch)
> <u>Brama raji</u> (Bloch)
> <u>Braina brama</u> (Bonnaterre)
> <u>Lepidotus brama</u>, (Bonnaterre)
> <u>Brama rayi</u> (Bloch)

Some investigators consider the Pacific and Atlantic pomfret to be the same species and thus use either <u>Brama</u> <u>raii</u> or <u>B. brama</u> to designate both. Mead (cited by Hitz and French 1965) feels, however, that while the North Atlantic and southern hemisphere populations are similar and should 'be designated <u>B. brama</u>, the North Pacific stocks should be considered a separate species 'rider 'he 'ame <u>B. japonica</u>. While the adults of <u>B. brama</u> and B. <u>japonica</u> are difficult to distinguish, the young differ markedly (Hart 1973).

The Pacific pomfret is also known locally as Ray's bream and the small scale pomfret (Trumble 1973), in Japan it is called shims gatsuo, and in Russia it is simply called brama (Lindberg et al. 1964).

The pomfret closely resembles the African pompano or Cuban jack in general appearance (Browning 1974). It has a deep, compressed body, a narrow caudal peduncle, and a deeply forked tail. The eyes are set well forward, between the highly arched forehead and underslung jaw according to Browning. The body coloration grades from steel gray dorsally to a bright silver below, with brownish-black on the snout and most fins (Hart 1973). After death the silver color fades to a dull brown or black (Van Cleve and Thompson 1938).

DISTRIBUTION

Members of the family Bramidae are world-wide in distribution, inhabiting both temperate and tropical oceans. They are found in the Atlantic Ocean, the Red Sea, the Mediterranean and the North Sea. In the Pacific they are recorded from off Australia, the Kamchatka Peninsula, and the Pacific Coast of Japan, Korea, the United States, and Canada (Grinols 1965).

The general distribution in the North Pacific Ocean of the species designated by some as Brama japonica is shown in Fig. 111.18.2. Wilimovsky (1954) gives the range as the California coast to the Gulf of Alaska. According to Mead and Haedrich (1965), however, one specimen was caught by a commercial trawler in the Bering Sea, and Hart (1973) reported that pomfret have been caught near Guadaloupe Island off Baja California. Brama japonica seems to have a trans-Pacific distribution, for in addition to being found off the coasts of California. Oregon, Washington, and Alaska, it also occurs on the Asian side of the Pacific (Grinols 1965). It is not known whether the eastern and western Pacific pomfret are separate stocks; according to Trumble (1973) they inhabit surface waters of slightly different temperature ranges, but they may interbreed because their distribution seems to be continuous across the Pacific.

Distribution in the Bering Sea

Fedorov (1973a) mentioned that pomfret migrate into areas of the Bering ant! Okhotsk Seas during the summer to forage. Few specimens are recorded as having been caught in the Bering Sea, however, although they are seasonally abundant in the central Aleutian Islands (Mead and Haedrich 1965; Hitz and French 1965). Wilimovsky (1964) reported their being found among the inshore fish on the northwest side of Unalaska Island. Gill nets and purse seines set in the Bering Sea by the Bureau of Commercial Fisheries in the summers of 1956, 1961, and 1962 failed to capture any pomfret (Hitz and French 1965). Gillnets set in the Bering Sea by Japanese salmon research vessels during 1967 to 1970 also failed to collect pomfret (Machidori and Nakamura 1971). There are indications that pomfret distribution is probably not limited by food availability but by surface water temperature (Trumble 1973). Unless there are seasons of unusually warm surface water (7 to 17°C), large concentrations of pomfret probably will not be found in the Bering Sea (Machidori and Nakamura 1971).
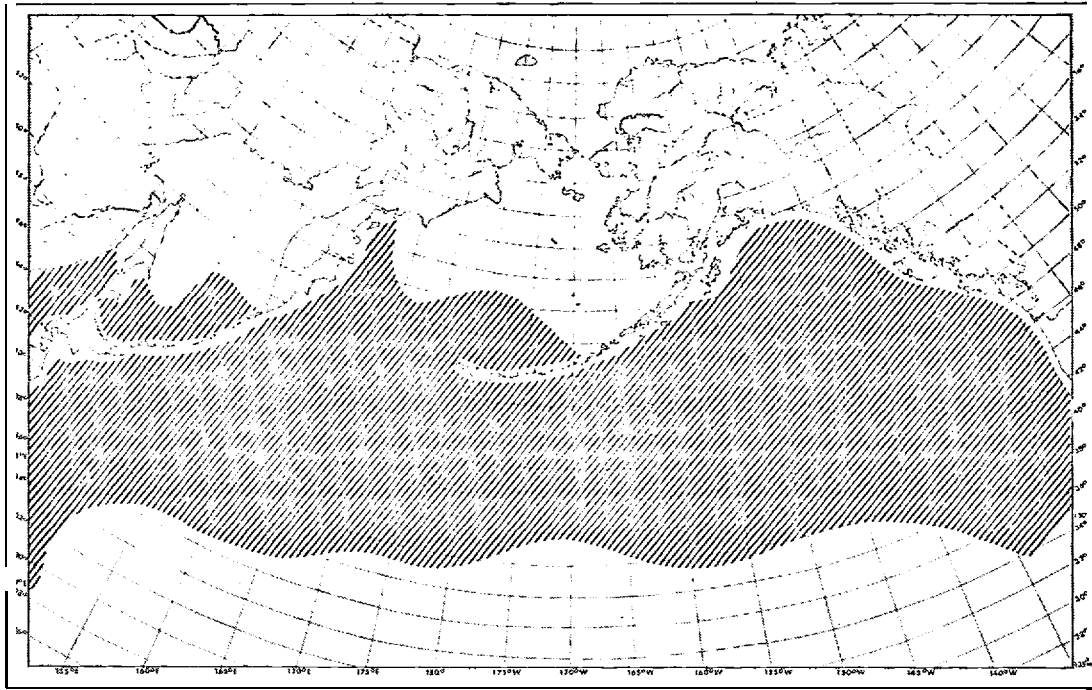
Figure 111.18.2 .--Distribution of pomfret (Brama japonica). No exact
   boundaries of the range have been defined (map drawn from information
   given in Pinckard 1957, Grinols 1965, Hitz and French 1965, Mead
   and Haedrich 1965, and data from Section IV of this report),

Distribution in the Gulf of Alaska

No information was found in the literature on the distribution of eggs,
larvae, or juveniles in the Gulf of Alaska.

Distribution of the adult Brama japonica in the Gulf of Alaska seems to
be limited seasonally by the temperature of the surface waters. During the
winter, pomfret are concentrated in the southern parts of their range, ex-
panding northward as the surface waters become warmer (Machidori and Nakamura
1971). Machidori and Nakamura found that pomfret were not caught north of
lat 40° N during March and April but by May and June they were captured
as far north as 45° N. In August and September, concentrations of pomfret
are found near the Aleutian chain. Pomfret seem to follow the northward
movement of the 100 C isotherm (Trumble 1973), increasing the seasonal range
in the Gulf of Alaska region from 500,000 to 750,000 square miles (Neave
and Hanavan 1960). Figure 111.18.3 illustrates this northward range expansion.
A specimen caught in a salmon trap at Cape Uyak, Kodiak Island (57″38′ N,
145°21′ W), during September 1937 is one of the most northerly records for
pomfret in the Gulf of Alaska. The Bureau of Commercial Fisheries exploratory
salmon survey in the Gulf of Alaska seemed to indicate that Brama japonica
inhabit waters with a surface temperature from 9.5 to 19° C, with the best

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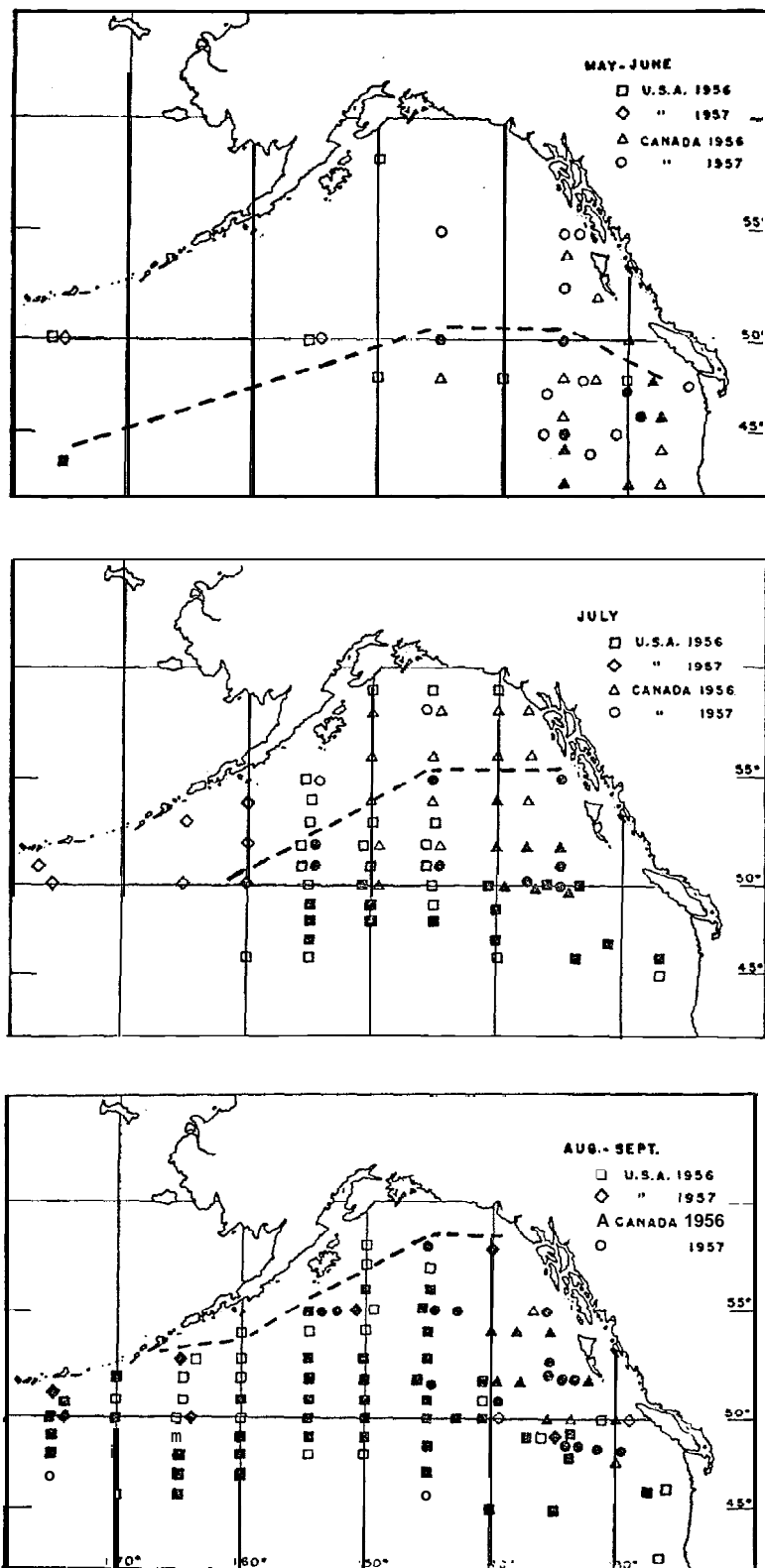
Figure 111.18.3 .--Distribution of pomfret in gillnet catches in the Gulf of Alaska, 1956-57. Broken line - approximate northern limit of catch records, black symbols - occurrences of pomfret, open symbols - fishing stations where pomfret were not taken. (From Neave and Hanavan 1960.)

rate of catch between 11 and 14° C (Hitz and French 1965). Japanese gill-netting and buoy line fishing in the northwestern Pacific indicated pomfret are caught in 7 to 14° C water, with a maximum catch at temperatures greater than 9° C (Machidori and Nakamura 1971). With the coming of winter and cooler surface water temperatures in the Gulf, pomfret migrate to the south out of the area, thus completing their yearly cycle (Trumble 1973).

Focal availability, while it may affect the local distribution of pomfret, does not seer to be a limiting factor in the northward migration. The northern limit of coho salmon, which has a similar diet, is much further north than that of pomfret, indicating the presence of suitable prey organisms outside the pomfret range (Machidori and Nakamura 1971).

<center>Vertical distribution</center>

Neave and Hanavan (1960) classified the pomfret as an epipelagic fish. This designation seems to be borne out by the fact that Brama japonica apparently is caught solely by purse seines and gill nets in near-surface water (Trumble 1973). Tuna longlines, groundfish otter trawls and shrimp trawls in the same location fail to catch pomfret.

Although pomfret may be found as deep as 200 meters (Fedcrov 1973a), the maximum depth at which they are found in any one locality is probably a function of the water temperature profile. Figure 111.18.4 illustrates this relationship-- the depth at which the greatest number is found appears to be temperature limited, the maximum depth depending on the depth of the thermocline. Time of day may also influence the vertical distribution because Machidori and Nakamura (1971) found indications that pomfret may undertake diurnal vertical migrations, occurring closer to the surface in early morning and in deeper waters around noon.
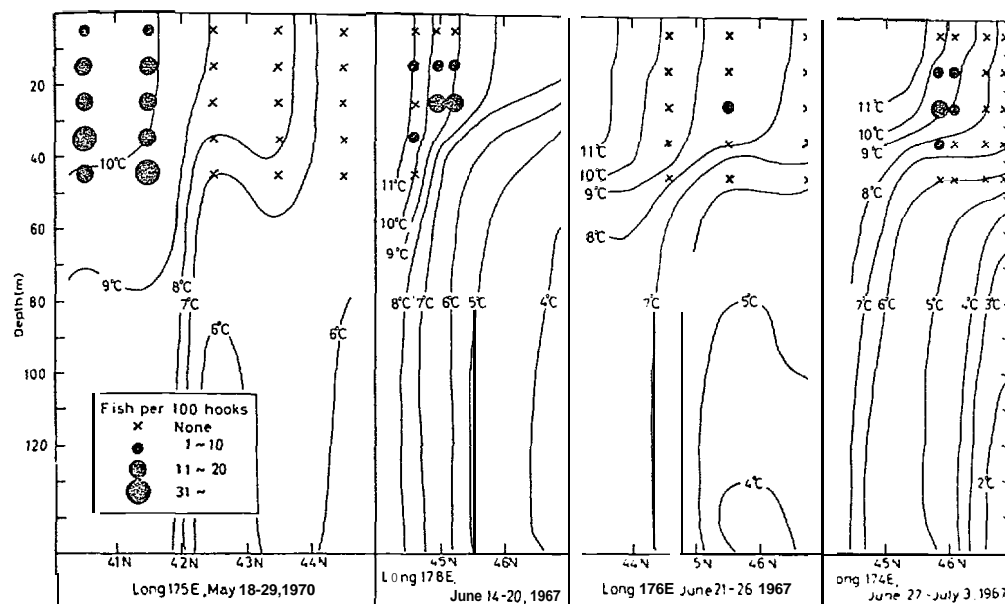
Figure 111.18.4 .—Vertical water temperature profiles and pomfret catches at 10 m intervals in buoy lines in the northwest Pacific, 1967 and 1970 (from Machidori and Nakamura 1971).

LIFE HISTORY

Reproduction

Very little concerning the reproduction and early life history of the pomfret
can be found in the literature, as these aspects of Brama japonica have
been largely unstudied (Trumble 1973). The adult sex ratio is probably 1:1,
as determined by Pinckard (1957) after examining 128 specimens and by Manzer
(1972) after studying 300 fish. By the age of four to five, pomfret are
sexually mature and are from thirty to fifty centimeters long (Trumble 1973).

The location of the spawning area is presently unknown, but spawning probably
occurs off the Mexican coast from lat 25 to 33° N as indicated by the capture
in this area of young specimens during the cruises of the California Coopera-
tive Oceanic Fisheries Investigations (Mead and Haedrich 1965). The exact
time of spawning is also unknown but, by process of elimination, Trumble
(1973) decided that spawning probably occurs in fall or early winter while
they are in the most southerly portion of their range. Spawning does not
seem to take place during the northern migration because the winter congre-
gations are composed of fish that had spawned previously. Once again, temp-
erature may play an important part in determining the location and time
of spawning, for the closely related North Atlantic pomfret, Brama brama,
spawns at temperatures in excess of 20° C, also in the southernmost part
of its range.

Pacific pomfret fecundity and frequency of spawning are also unknown, but
the silver pomfret found in the Arabian Sea apparently spawns at least twice
in a given season (Trumble 1973). Likewise, little is known about the nature
and development of Brama japonica eggs, but Trumble feels that, like the
eggs of most oceanic fish, they are probably pelagic.

Nutrition and Growth

Growth

The Pacific pomfret is known to attain a length of 122 cm (4 ft.) according
to Pinckard (1957), but this size is very rarely caught. The largest specimens
generally caught in exploratory fishing surveys were 49 or 50 cm, and fish
of 30 to 45 cm were more common (see Fig. 111.18.5) (Pinckard 1957, Machidori
and Nakamura 1971). The mesh size of the gill nets could well be a limiting
factor in the size of the fish taken because, according to Hitz and French
(1965), 93% of the pomfret caught in the salmon gillnetting surveys of 1960
to 1961 were taken in the two largest mesh sizes. An even larger mesh size
might have caught larger fish.

Figure 111.18.6 shows the estimated growth rate of Brama japonica plotted
by Machidori and Nakamura (1971). Unfortunately, the data are primarily
based on a rather limited size range of specimens and may not be too accurate
for either smaller or larger fish. Pomfret of 34.6 and 40.2 cm (the length
frequencies which dominated in the Japanese salmon survey catches) were
found to be 4 and 5 years old, respectively (Machidori and Nakamura 1971).
Using this information, Trumble (1973) estimated that the age of 120 cm
fish might exceed 20 years.
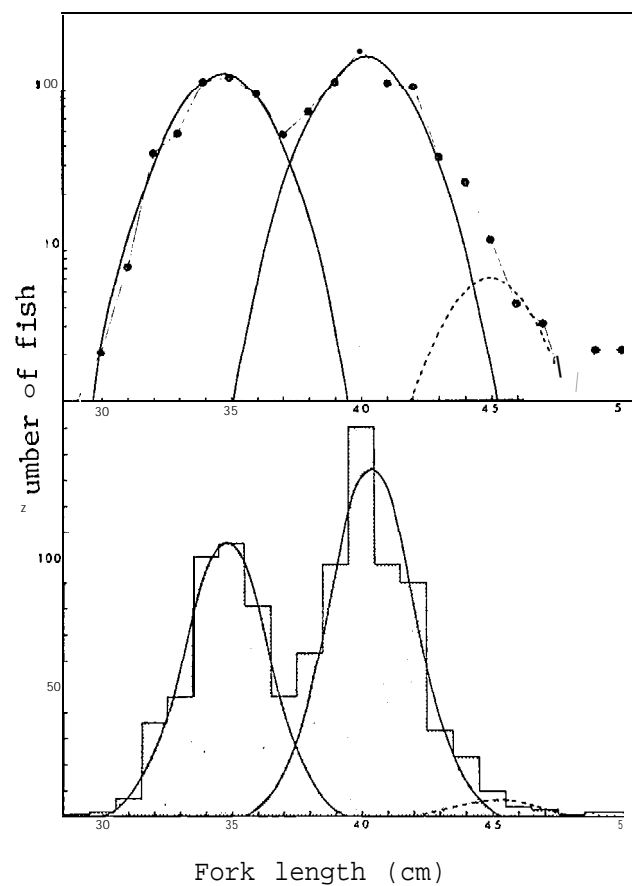
Figure 111.18.5.--Length distribution of pomfret caught in gillnets, buoy lines, and longlines in the area of lat 39 to 47°N and long 174 to 179° E in early June to early July 1967 and in May 1970 (from Machidori and Nakamura 1.971).
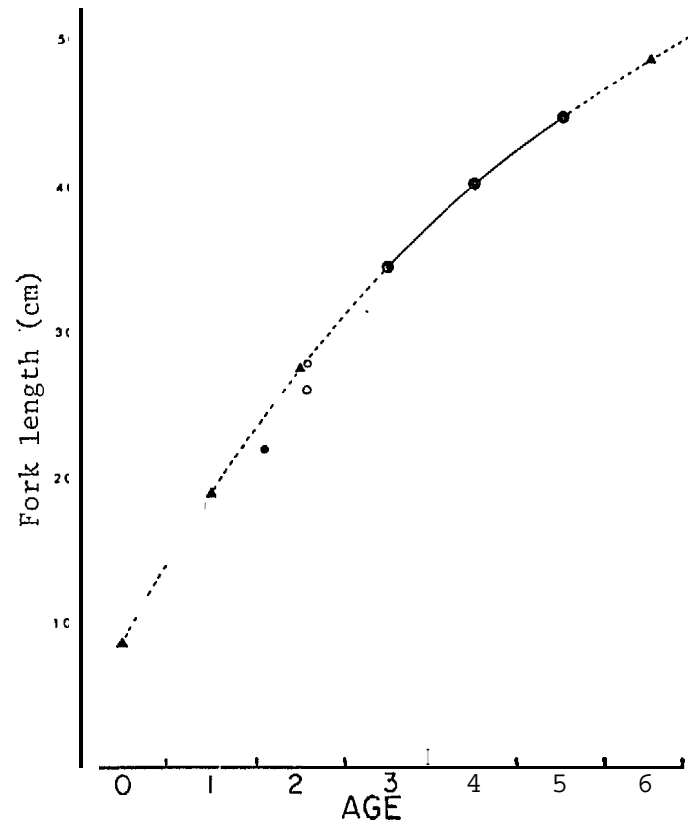
Figure 111.18.6.--Estimated growth of pomfret (from Machidori and Nakamura 1971).

Length-weight relationships for pomfret have been calculated by Machidori and Nakamura (1971) in the northwest Pacific Ocean and by Manzer (1972) in the Gulf of Alaska. In both cases, pomfret of the lower third of the known size range were used since larger specimens were unobtainable. The length-weight relationship for northwest Pacific pomfret was found to be $W = 2.37 \times 10^{-4}L^{2.29}$ (Fig. 111.18.7). Manzer (1972) found that while the length-weight ratio of Gulf of Alaska pomfret did not appear to differ between males and females, it did differ significantly between years 1956 ($W = 2.068 \times 10^{-4}L^{2.774}$) and 1957 ($W = 1.539 \times 10^{-4}L^{2*641}$).
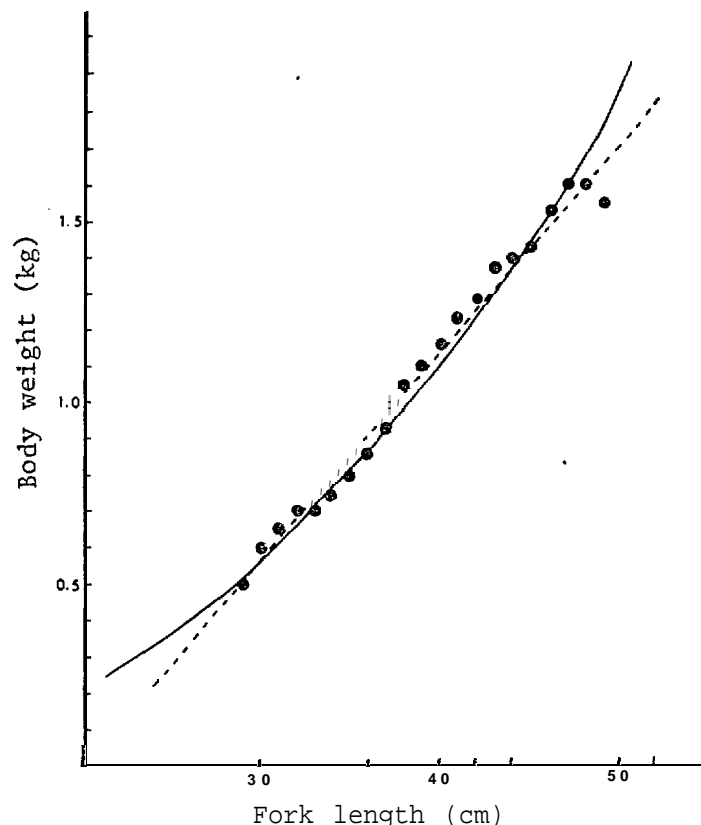
Figure 111.18.7.--Relationship of fork length of Pacific pomfret to body weight (from Machidori and Nakamura 1971).

Food and Feeding

Squid and fish seem to make up the greatest proportion of the diet of pomfret in the North Pacific. Pinckard (1957) examined the stomach contents of 45 pomfret caught off the British Columbia coast, and in the 20 stomachs that contained food, squid occurred 13 times, fish 8 times, and shrimp and amphipods each once. The diet of pomfret caught in the northwest Pacific seems to be very similar (Fig. 111.18.8), with the proportion of squid and fish varying somewhat with the month, and decapods, euphausiids, pteropods, and amphipods making up a very minor portion of the diet.
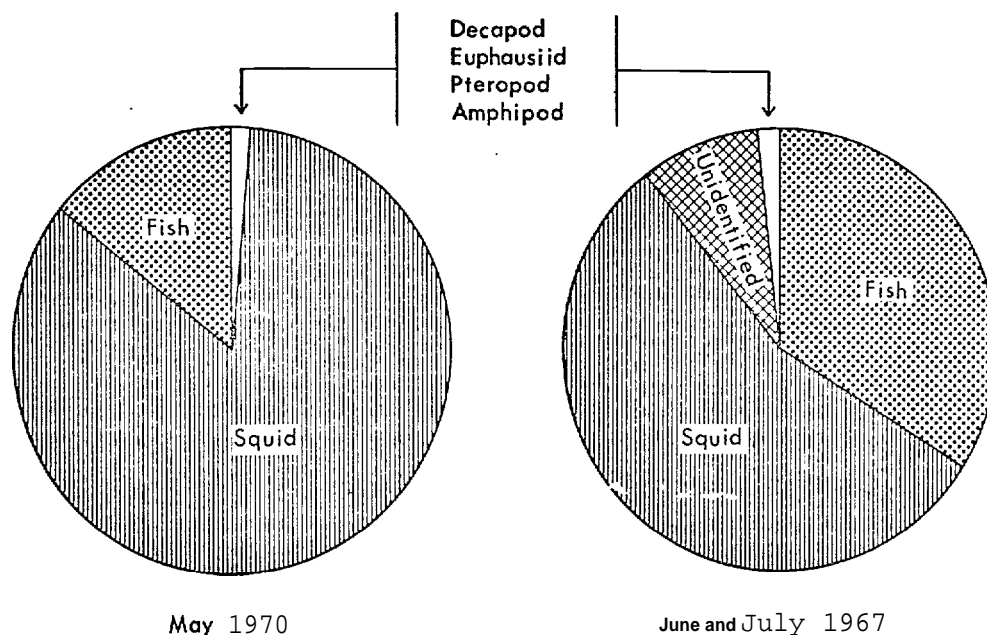
Figure 111.18.8.--Weight composition of stomach contents of pomfret
   in the area lat 39-47°N, long 174-179°E (from Machidori and
   Nakamura 1971).

Predators and Competitors

While no mention is made in the literature of predators on pomfret in the
Gulf of Alaska, fur seals have been found to take pomfret off the coasts
of British Columbia and California (North Pacific Fur Seal Commission 1962).
Since fur seals (and several other marine mammals) are largely opportunistic
feeders, it is not unlikely that they occasionally catch and eat pomfret
when the chance arises, but these fish probably do not constitute a very
large proportion of the diet of marine mammals.

A possible competition for food may exist between pomfret and coho salmon.
They both have similar diets, and the weight of the salmon stomach contents
were found to increase in those areas where pomfret are not present (Machidori
and Nakamura 1971).

Behavior

At certain times of the year, pomfret may form schools. Atlantic pomfret
off the coast of Spain form post-spawning congregations during the winter
months (Trumble 1973) , and it is quite possible that a similar occurrence
takes place off the Pacific coast of North America. Erratic abundances of
Pacific pomfret have been mentioned in the literature (Pritchard 1930, Van
Cleve and Thompson 1938, Hitz and French 1965, Browning 1974), indicating
that they may form schools or loose aggregations at other times of the year
also.

As previously discussed in the section on distribution in the Gulf of Alaska, pomfret participate in yearly migrations. During the spring and summer months, the Pacific pomfret moves north from off the California coast to British Columbian and Alaskan waters. At this time, some pomfret have been shown to average 15 to 17 km (8 to 9 miles) of northward movement per day (Neave and Hanavan 1960). This northward migration is well documented by the seasonal changes in availability of pomfret to gill nets and purse seines along the route (Hitz and French 1965, Machidori and Nakamura 1971). In contrast, little is known of the return migration to southern waters in the fall (Neave and Hanavan 1960).

In addition to north and south migrations there are indications of trans-oceanic movements. Westward flowing north equatorial currents may serve to transport pelagic eggs and larvae and thus distribute them throughout much of the North Pacific (Trumble 1973). The Bureau of Commercial Fisheries caught pomfret in salmon gill nets as far west as long 175° W and the Japanese surveys have caught them from 155° E to 180° (Hitz and French 1965, Machidori and Nakamura 1971). Tagging studies would be necessary to determine the extent of intermingling of the Asian and American stocks.

As previously mentioned, Brama japonica may also perform daily vertical migrations because Machidori and Nakamura (1971) found them closer to the surface in the early morning and in deeper waters around noon. A diurnal migration may also at least partially explain why pomfret are more likely to be caught in surface gill nets at night than during the day.

POPULATION STRUCTURE AND DYNAMICS

As the Pacific pomfret has not been commercially fished in the northeast Pacific very little is known about the population structure of the stocks. The size and age composition of the pomfret caught in salmon gill nets is very likely biased by the size of the mesh used and may not be representative of the whole population. Four- and five-year-old fish with respective lengths of approximately 34.6 and 40.2 cm dominated in the gillnet, buoy line, and longline catches of the Japanese salmon surveys (Machidori and Nakamura 1971). Although larger fish are known to exist, none were captured by the gear used, thus an accurate size composition cannot be obtained until a more representative sampling method is found. On the ether hand, the sex ratio of the mature fish is quite likely 1:1 as demonstrated by both Pinckard (1957) and Manzer (1972), for there are no indications that the gear used is selective for sex.

Abundance is another parameter of the Pacific pomfret populations that is difficult to estimate. Concentrations of pomfret seem to be erratic in their movements. Pritchard (1930) mentioned that on August. 6, 1929, pomfret were so plentiful on the west coast of one of the Queen Charlotte Islands that fishermen had difficulty in keeping them off their hocks, but by the next day they had evidently moved elsewhere for no more were caught in that location. Similar reports of large concentrations of pomfret in the Aleutians (Browning 1974), the Gulf of Alaska (Van Cleve and Thompson 1938), and off Vancouver Island (Hitz and French 1965) have stimulated interest in their commercial exploitation. During the high seas salmon gill netting survey conducted by the Bureau of Commercial Fisheries in 1955-61, a total of 4,425 pomfret were taken (Larkins 1964) which, according to Trumble (1973), amounted to one-sixth of the total catch.

No estimates of natural or fishing mortality are available at this time,
but Mead and Haedrich (1965) mentioned that in the winter large numbers
of pomfret are caught by the cooling water in the north and are stranded
and die.

FI SHING

History of the Fishery

To date, pomfret has been considered one of the underutilized species in
the Gulf of Alaska. There is no mention in the literature of there being
any extensive native fishery, possibly because the fish only sporadically
venture into inshore waters where they would be available to local fisher-
men. In the early 1900's fishing vessels such as the cod-fishing schooner
Sophie Christenson took considerable numbers of the bright fish if they
happened to chance upon a congregation (Van Cleve and Thompson 1938). Ac-
cording to Larkin and Ricker (1964), British Columbia fishermen made some
attempts in the late 1950's to fish pomfret commercially, but these proved
unsuccessful when no dependable concentrations were found.

Fishing gear

Pomfret have generally been caught incidentally while fishing for other
species. Only surface gear, such as gill nets, purse seines, and near-surface
troll" lines have caught pomfret (Neave and Hanavan 1960). Nighttime gillnet
sets generally catch more fish than do sets made in the daytime (Pinckard
1957), and the larger mesh sizes ($4\frac{1}{2}$ and $5\frac{1}{4}$ inches) have also proved more
efficient in catching pomfret (Trumble 1973). During the Bureau of Commercial
Fisheries salmon surveys, the largest gillnet catches were in the western
Gulf of Alaska and the central Aleutians, while the greatest purse seine
hauls of pomfret were in the eastern Gulf of Alaska (Hitz and French 1965).
Off Spain, where light-weight longlines 90 to 110 meters long are used,
catch rates often reach 60 to 70 Atlantic pomfret per 100 hooks, but in
the Pacific, midwater longlines were unsuccessful at catching pomfret (Trum-
ble 1973).

POTENTIAL CONTRIBUTION TO DOMESTIC AND INTERNATIONAL ECONOMY

Pomfret at present are fished commercially only off Japan and off Spain
(Trumble 1973). As the Pacific pomfret closely resembles the African pompano
in appearance and taste, there are some hopes that it may become a valuable
resource like the pompano (Browning 1974). The main problem in developing
a commercial pomfret fishery has been the inconsistency of the catches.
It is possible that if gear were specifically designed to catch pomfret
and if the roving concentrations of fish could 'ce located, enough could
be caught to support a moderate industry. While it may prove feasible to
fish for pomfret in the Gulf of Alaska the most likely fishing area might
be off the California ccast when the fish form their pre-migration congregations
(Trumble 1973).

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SUGGESTIONS FOR FUTURE RESEARCH

There is a general dearth of knowledge about the Pacific pomfret. Virtually nothing is known about the reproduction, eggs, or larvae, and little is known about the size and composition of the stocks. Exploratory fishing with a variety of kinds of gear should be conducted in order to determine whether they exist in commercial quantities and, if so, the most efficient gear for catching them.

PACIFIC SANDFISH (Trichodon trichodon)
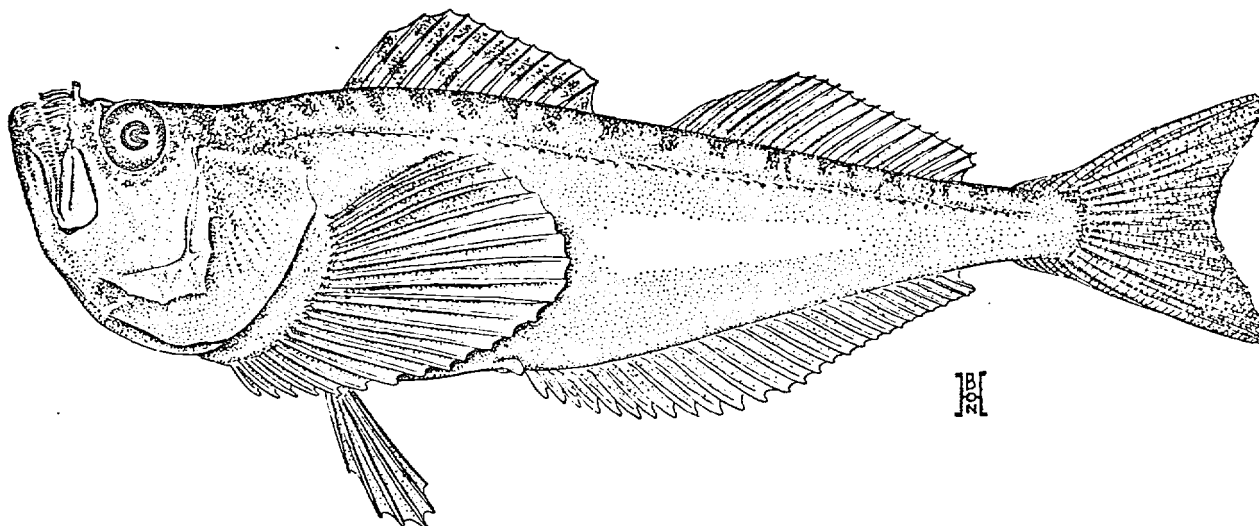
Figure 111.19.1 .--Pacific sandfish, Trichodon trichodon (from Part 1973).

IDENTIFICATION

The Pacific sandfish is known in the Soviet Union as obyknovennyĭ volosozub
(common hairtooth) and in Japan as hatahata (Quast and Hall 1972, Fedorov
1973a).There may be some confusion in the literature, however, because a
related species, the Japanese sandfish, Arctoscopus japonicus, is found in
some of the same geographical areas (Wilimovsky 1954). The Japanese sandfish
does not grow as large as the Pacific sandfish and has fewer dorsal fin spines
(10 to 11 instead of 14 to 15), but is otherwise fairly similar (Mineva 1955,
Herald 1961).

Trichodon trichodon (once designated Trichodon stelleri in British Columbia)
is a moderately small fish with an elongate, somewhat compressed body (Clemens
and Wilby 1961). The notable features include a total absence of scales, .
a nearly vertical mouth with a fleshy fringe lining the lips on both sides,
and stout pectoral fins with outspread edges (Herald 1961, Hart 1973). Eyes
that are high on the head, the presence of five sharp spines on the precpercle,
and a high lateral line canal provide additional recognition clues (Clemens
and Wilby 1961, Hart 1973). The sandfish has a light brown back, a silvery
belly, and above the lateral line are dark , irregular patches which merge
into a streak toward the tail (Clemens and Wilby 1961, Hart 1973).

DISTRIBUTION

Wilimovsky (1954) gives the range of Trichodon trichodon as the Bering Sea
to California and the distribution of Arctoscopus japonicus as the Bering
Sea to southeast Alaska and Japan. Two Soviet investigators, Mineva (1955)
and Musienko (1970), state that T. trichodon occurs on the Asian side of
the North Pacific as well, as far south in the Sea of Okhotsk as the island
of Hokkaido, Japan. Hart (1973) also mentions Pacific sandfish as being found
off Kamchatka and Mednyy Island in the Commander Islands. Thus, Trichodon
trichodon may be found off Japan as well as in the eastern Pacific Ocean,
or there may be some confusion with the Japanese sandfish Arctoscopus japonicus.

On the North American side the Pacific sandfish is found as far south as
San Francisco Bay in California (Hart 1973). In Alaskan waters they have
been reported from southeast Alaska, the Gulf of Alaska (especially near
the Kenai Peninsula and the Shumagin Islands) (Jordan and Gilbert 1899, Quast
and Hall 1972), along the Aleutian chain, and in the Bering Sea (Hart 1973).
Wilimovsky (1964), in his survey of the inshore area of the Aleutian Islands,
found sandfish at Attu, Buldir, Kiska, Tanaga, Great Sitkin, Igitkin, Atka,
the southwest coast of Umnak, and northwest coast of Unalaska, and the Kren-
itzin Islands. In the Bering Sea they have been caught at Herendeen Bay on
the Alaskan Peninsula (Gilbert 1895); in Bristol Bay (Gilbert 1895, Baxter
1975); and near Nunivak Island, Bering Island, and around St. Paul Island
in the Pribilof Islands (Jordan and Gilbert 1899).

Although they have been found in shallow water buried in the sand with only
their eyes and jaws exposed (Herald 1961, Clemens and Wilby 1961), evidently
they are pelagic at some periods of their life, for they are frequently caught
by pelagic gear. Scheffer (1959) also mentioned their being caught in kelp
beds.

Fedorov(1973b) reported finding Trichodon trichodon in the Bering Sea at
depths ranging from 20 to 250 meters. However, according to a table presented
by Shuntov (1963), the predominant habitat of sandfish in the southeastern
Bering Sea is depths of 50 to 75 meters. Depth preference may vary with the
seasons, for the Japanese sandfish Arctoscopus is said to live at approxi-
mately the 140 meter (450 ft) depth during non-spawning seasons, then moves
into one-meter shallows to spawn (Herald 1961).

LIFE HISTORY

Reproduction

Very little is known about the life history of the Pacific sandfish. Mineva
(1955) made a fecundity estimate by counting all the eggs from the ovaries
of two sandfish specimens of 184 and 252 mm in length. The 184 mm fish con-
tained 4,010 eggs and the 252 mm one held 7,270. A count of only the large
yolked eggs from various specimens yielded a range of 310 to 1,862 eggs per
female. Mineva found several different size groups of eggs in the ovaries,
indicating that the immature eggs would be either reserved for a later
spawning or resorbed. No estimate of the spawning time of Trichodon trichodon
is given in the literature, but a female with mature eggs was found off
British Columbia in late February (Clemens and Wilby 1961). Mature eggs,
which are yellow or slightly orange, vary in diameter from 0.1 to 1.0 mm
with an average diameter of 0.54 mm (Mineva 1955). Eggs of the Japanese sand-
fish are usually larger (0.8 to 3.4 mm, average 1.8 mm) and are laid in
spherical capsules of about 750 eggs (Mineva 1955, Herald 1961).

Nutrition and Growth

According to Herald (1961), Japanese sandfish can take up to two months to
hatch, and it is supposed that the Pacific sandfish embryo has a similar
development time, depending on the water temperature. Although both Trichodon
trichodon and Arctoscopus japonicus have been known to reach a maximum of
305 mm (12 in.) (Herald 1961), the lengths of 55 Pacific sandfish caught

off the southwest coast of Kamchatka ranged in fork length from 171 to 260 mm, with an average of 218 mm (Mineva 1955). Females are generally larger than males, with average lengths of 220.9 and 189.6 mm, respectively. The weight of the same specimens varied from 51 to 180 grams and averaged 114.0 grams for females and 72.5 grams for males. Japanese sandfish are generally smaller, with fork lengths of 101 to 220 mm and weights of 16 to 96 grams (Mineva 1955).

Pacific sandfish have been found to consume small crustaceans such as mysids, amphipods and cumaceans (Mineva 1955, Kenyon 1956). Mineva discovered that sandfish feed rather intensively in July and September and that the less fat the individual, the more intensively it feeds.

Predators

Fish have been known to prey on Trichodon because sandfish have been taken from the stomach of a cod in Bristol Bay (Gilbert 1895) and the stomach of a chinook salmon caught off British Columbia (Clemens and Wilby 1961). Pacific sandfish are also consumed by fur seals, especially in the vicinity of St. Paul Island in the Pribilofs where sandfish made up 94.2% of the volume of the 27 fur seal stomachs which were found to contain food at the seal harvest in 1954 (Kenyon 1956). Sandfish appear to be only a minor part of the diet of pelagic fur seals, however, as indicated by the investigations of Wilke and Kenyon (1957), the North Pacific Fur Seal Commission (1962, 1971, 1975), and the Marine Mammal Biological Laboratory (1970).

Behavior—Migrations

Little is known about the movements of the Pacific sandfish, but Herald (1961) reported the Japanese sandfish has been found to migrate from its usual depth of 140 meters to spawning grounds only one meter in depth during the month of December. After hatching, the young fish remain in the shallows for about three months before moving into deeper water.

POPULATION STRUCTURE AND DYNAMICS

The only indication of the sex composition of Pacific sandfish is from the study of 25 specimens caught off the southwest coast of Kamchatka in which 4 were found to be males and the remaining 21 were females (Mineva 1955). Abundance is difficult to estimate, for in most cases their capture has been incidental by probably inappropriate gear. Jordan and Gilbert (1899) , however, reported that the sandfish was quite abundant around St. Paul Island and it was often found cast up on the beaches by the surf.

FISHING AND POTENTIAL CONTRIBUTION TO DOMESTIC AND INTERNATIONAL ECONOMY

While the Pacific sandfish is not utilized to any extent along the North American coast, the Japanese sandfish is reportedly an important food item in certain parts of Japan (Herald 1961), and perhaps someday it will find similar useage in Alaska.

PROWFISH (<u>Zaprora</u> <u>silenus</u>)
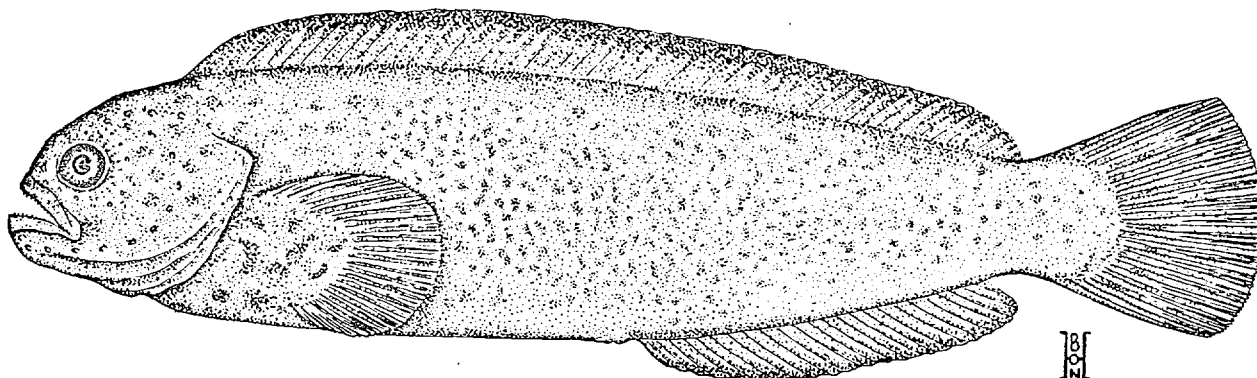
Figure III.20.1.—Prowfish, <u>Zaprora</u> <u>silenus</u> (from Hart 1973).

IDENTIFICATION

The prowfish, <u>Zaprora</u> <u>silenus</u>, or highbrow as it is sometimes referred to,
is the only species making up the family Zaproridae (Scheffer 1940, Clemens
and Wilby 1961). According to Chapman (1937), Jordan initially placed this
species in a family of its own but considered that it might be distantly
related to <u>Icosteus</u>, <u>Ichichthys</u>, <u>Shedophilus</u>, and <u>Centrolophus</u>.

<u>Zaprora</u> <u>silenus</u> is readily recognized by its elongate body, lack of pelvic
fins. absence of a lateral line canal. and compressed head with a blunt
snout and high "brow" (Hart 1973). Instead of a lateral line canal, the
prowfish has several rows of enlarged pores on the head and lower jaw which
are sometimes ringed by white. The dorsal surface and sides are grey, green
or brown, fading into a light tan on the ventral surface (Hart 1973). Immature
specimens often have seven dark vertical bars on the dorsal fin and three
bars on the anal fin (Chapman 1937).

DISTRIBUTION

General distribution

Wilimovsky (1954) reports the range of the prowfish as being from California
to the Gulf of Alaska along the Pacific coast of North America. Specimens
have been caught off Newport, Oregon (Schultz and Harvey 1945), in Juan
de Fuca Strait, along the southwest coast of Vancouver Island (Chapman 1937),
near the Queen Charlotte in British Columbia (Dymond 1928), near Kodiak
Island in the Gulf of Alaska, and along the Aleutian chain (Chapman 1937).
In the northwest Pacific they have been found near the Commander Islands,
along the western coast of Kamchatka, and near Japan (Grinols 1965, Hart
1973).

Specific distribution in the Gulf of Alaska and eastern Bering Sea

Figures 111.20.2 and 111.20.3 show the locations reported in the literature
where various prowfish specimens were obtained. Most fish were taken from
along the Aleutians and near Kodiak Island, but this pattern may be due
to the concentrated research effort in these areas rather than being a
reflection of the true distribution and abundance of the species. In the
Aleutians, prowfish have been found at Akutan Island (Chapman 1937), Umnak
(Hart 1973), and as far west as Attu (Scheffer 1940). No records were found
in the literature for distribution of this species in the Bering Sea but
the analysis of historical data in Part IV of this report indicates that
they are found in the Bering Sea at least out to the continental shelf.

Because of the lack of data on this species, it is difficult to generalize
its seasonal distribution. In its habitat preference, it appears to be pelagic
or bathypelagic; the young are found primarily at depths from 29 to 357
meters and the adults from 20 to 550 meters (Hart 1973, Fedorov 1973a).
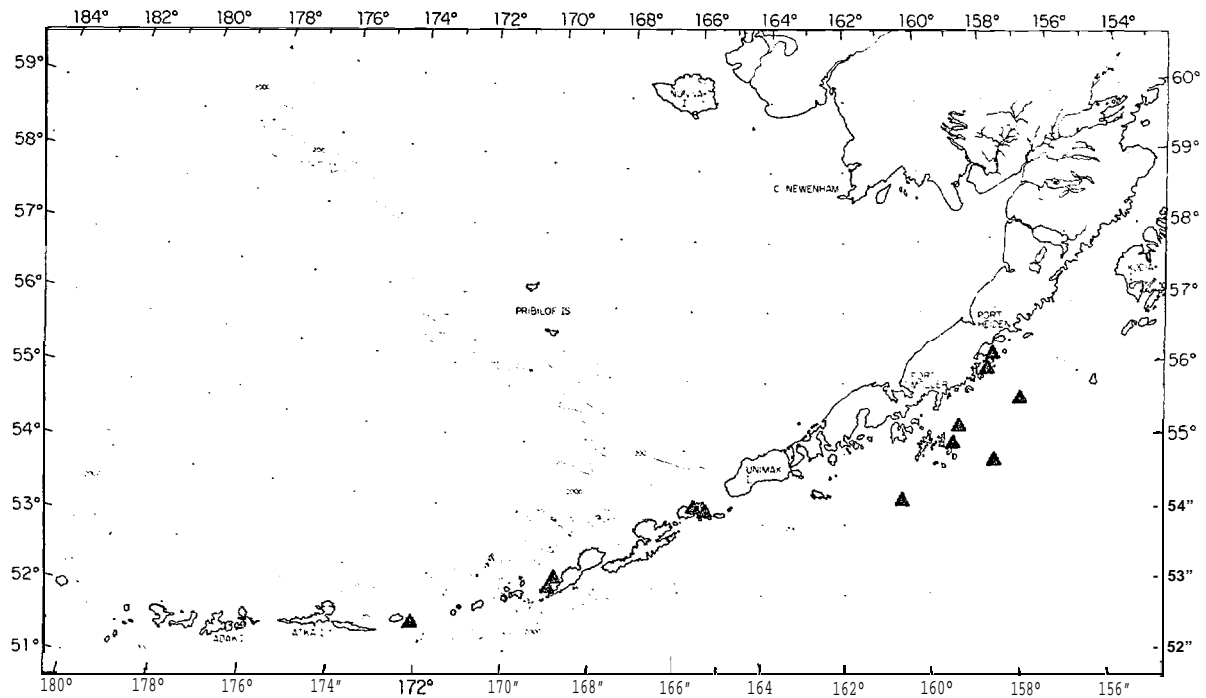
Figure 111.20.2.--Distribution of prowfish along the Aleutian Island
    chain (data from Schultz 1934, Chapman 1937, Scheffer 1940, Aron
    1960b, Wilimovsky 1964).
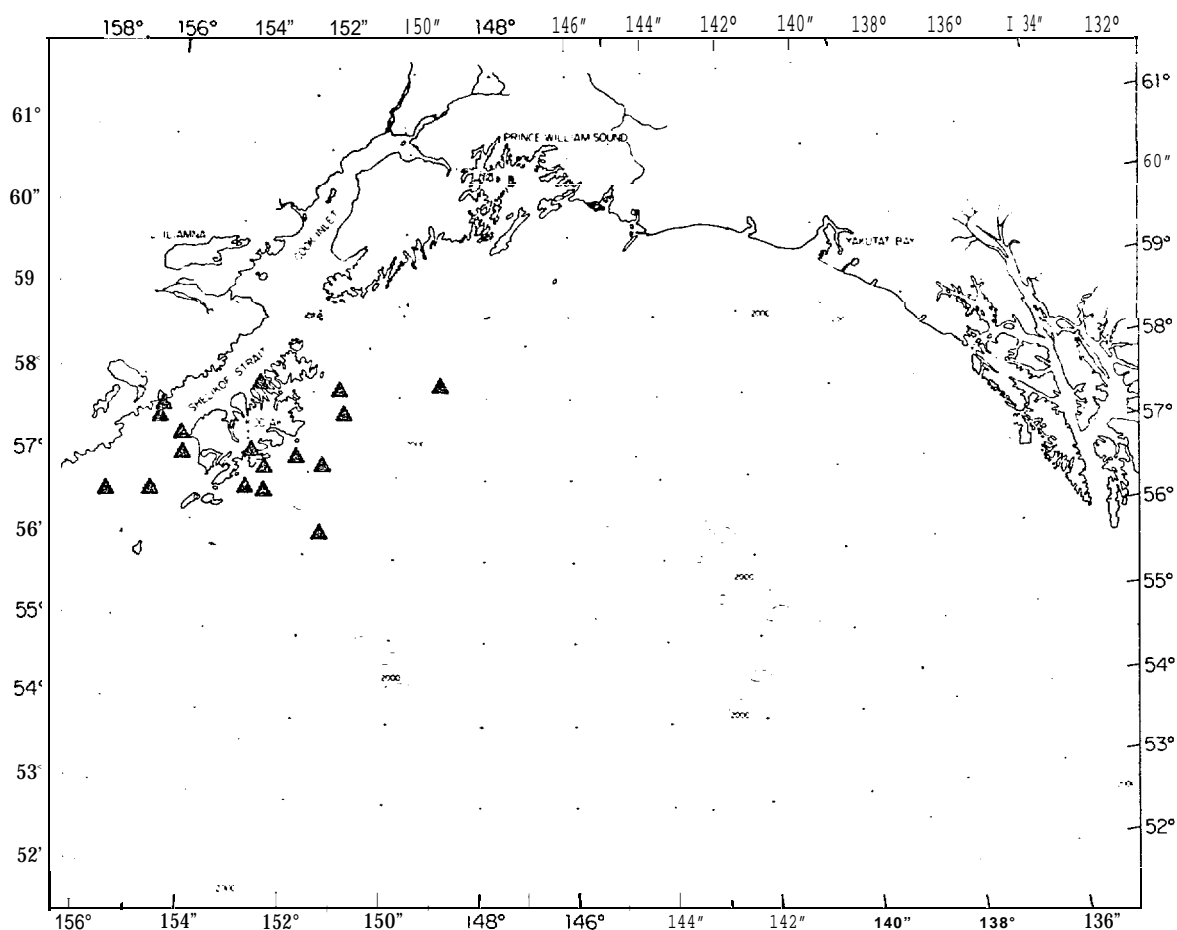
Figure 111.20.3 .--Distribution of prowfish in the Gulf of Alaska
(data from Kendall 1914, Schultz 1934, Chapman 1937) .

LIFE HISTORY

There is virtually no information at present on the life history of Zaprora
silenus. The greatest length recorded is 880 mm (34.5 in.), the length of
a specimen caught near Anthony Isle, British Columbia (Dymond 1928). Scheffer
(1940, 1959) observed an association of an immature prowfish with a large
orange jellyfish Cyanea. The fish followed the drifting motion of, the medusa,
maintaining a position about one foot below the hanging tentacles, then
sought protection in the manubrium when an attempt was made to catch it.

ABUNDANCE AND DENSITY

Although the total known number of prowfish specimens was only thirteen
in 1938 (Scheffer 1940), Grinols stated in 1965 that it was "not rare" in
the northeast Pacific Ocean.

FISHING & POTENTIAL CONTRIBUTION TO DOMESTIC AND INTERNATIONAL ECONOMY

There is no commercial fishery for this species at the present time. A fishery
might develop, however, if suitable quantities of prowfish are found and
if efficient gear to catch them were to be developed, for the red flesh
is firm and attractive (Clemens and Wilby 1961).

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PACIFIC SAND LANCE (Ammodytes hexapterus)
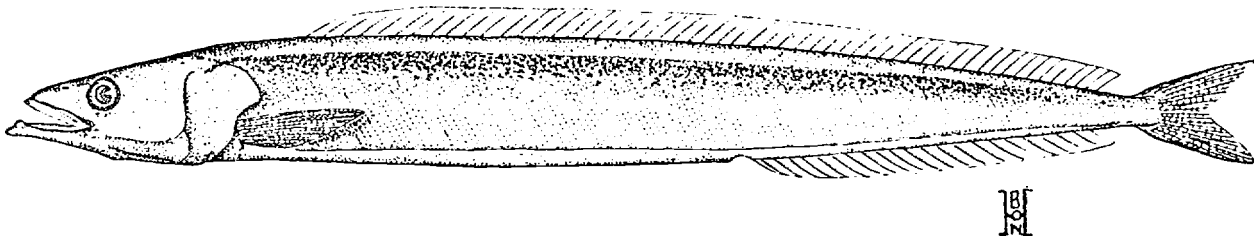
Figure 111.21.1 .--The Pacific. sand lance, Ammodytes hexapterus
(from Hart 1973) .

IDENTIFICATION

The systematic of the sand lance family, Ammodytidae, is at present very
ccnfused, especially for the sand lance populations in the Atlantic and
western Pacific Oceans. There is a wide variation in the meristic and morpho-
metric characters which are the primary basis for species separation, but
the life histories of the different sand lance groups appear to be similar
(Trumble 1973). At present , most investigators refer to the eastern Pacific
sand lance as a single species, Ammodytes hexapterus, but in the past many
different scientific names have been applied to it (from Andriyashev 1954,
Walters 1955, Hart 1973):

> Ammodytes hexapterus Pallas 1811
> Ammodytes americanus Bean 1881
> Ammodytes personatus Jordan and Gilbert 1899
> Ammodytes alascanus Evermann and Goldsborough 1907
> Ammodytes tobianus Lindberg and Dul'keit 1929
> Ammodytes tobianus Ark. Zool. Stockh. 1931
> Ammodytes tobianus personatus Popov 1931
> Ammodytes hexapterus hexapterus Lindberg 1937

The relationships between the eastern Pacific sand lance and those forms
in the western Pacific are uncertain but , according to Kasahara (1961),
the sand lance found in the northern Kuriles and northward to the Bering
Sea are considered to belong to A. hexapterus , while those near Japan are
designated A. personatus. Walters (1955) felt that the North Atlantic sand
lance, A. marinus, was the same as A. hexapterus of the North Pacific Ocean,
but some still regard them as separate species while others accord them
subspecific standing as A. hexapterus marinus and A. hexapterus hexapterus,
respectively (Andriyashev 1937, Walters 1955).

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Common names for the sari? lance abound because of its wide distribution.
In the United States it has been called Pacific sand lance, arctic sand
lance (Fedorov 1973b), sandlaunce (Bean 1887), sand eel (Berg et al. 1949),
and needlefish (Scheffer 1959). In the Soviet Union it is known as
dal'nevostochnaya mnogozvonkovaya peschanka and obyknovennaya peschanka
and in Japan as ikanago or kits-ikanago (Fedorov 1973b).European names include
sandspirling, equine, lançon, siil, and lant (Bean 1887, Berg et al. 1949).

Hart (1973) described the sand lance as having a very elongated body with
a high lateral line, a ventral longitudinal fold extending the body length,
and a series of approximately 150 diagonal folds running down the sides.
The head is long with a low pointed snout and an upward directed mouth.
No spines are present in the long unpaired fins, the tail is deeply forked,
and there are no pelvic fins. The color shades from grey or green dorsally
to iridescent silver on the sides and belly,

DISTRIBUTION

General Distribution

Because of present confusion in the systematic of sand lances, the exact range
of Ammodytes hexapterus is difficult to delineate, especially on the Asian
side of the Pacific Ocean. Most investigators agree that this is the species
represented in the Chukchi Sea, the Bering Sea, and the Sea of Okhotsk,
but some scientists feel that a different species' inhabits the waters surrounding
Japan (Andriyashev 1954, Walters 1955, Kasahara 1961). The Pacific sand
lance is found along the North American shores from southern California
to Alaska, and along the Arctic coast of Alaska and Canada to the mouth
of the ClearWater River in eastern Hudson Bay (Hart 1973).

Specific Distribution in the Eastern Bering Sea and Gulf of Alaska

Distribution of eggs and larvae

Because the eggs and yolk sac larvae are demersal (Trumble 1973), they are
found only on the spawning grounds, buried in the sand. After the yolk sac
is absorbed the larvae become planktonic and are carried by the winds and
currents farther offshore and over greater depths (Inoue et al. 1967, Kashkina
1970), thus the larvae become more dispersed as the season progresses.
According to Kobayashi (1961), sand lance larvae were found in the Bering
Sea as far north as lat 55"N in June and lat 600N in July. It was not until
August that some larvae were found north of 600N (see Fig. 111.21.2). Inoue
et al. (1967) noted a diurnal difference in the vertical distribution of
sand lance larvae off the coast of Japan; during the day the larvae seemed
to concentrate at the six to ten meter depth but at night they were found
deeper. Ichthyoplankton surveys have found large concentrations of sand
lance larvae in Bristol Bay off Cape Newenham (Kashkina 1970) and near Kodiak
Island on Portlock and Albatross Banks (Favorite, Ingraham, and Fisk 1975).
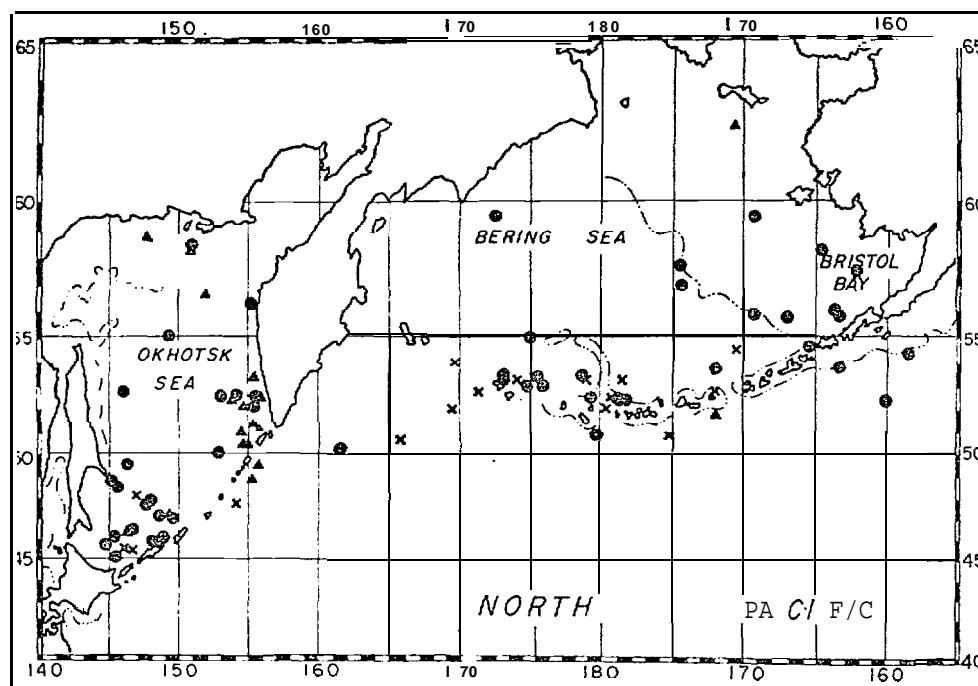
Figure 111.21.2 .--Ccl lection locations of larvae and young of the
Pacific sand lance, Ammodytes hexapterus, in the northwestern
Pacific, 1955-60. X - June, ⊕ - July, ▲ - August (from Kobayashi
1961) .

Distribution of adults

Certain aspects of its anatomy and ecological adaptations result in the
aduit sand lance being found in a particular type of habitat, During the
day the sand lance feeds in large congregations at various depths, but because
it has no swim bladder and thus must keep actively swimming to maintain
its position in the water column, it conserves its energy when not feeding
by resting on the bottom (Trumble 1973). Its habit of burying itself in
the substrate (possibly as a form of protection from predators) (Nikol'skii
1954) may be at least partially responsible for its preference for sand
and fine gravel bottoms. Acccrding to Inoue et al. (1967) and Trumble (1973),
the optimum substrate consists of coarse sand C.35 to 1.30 mm in grain size,
mixed with as much as 30% by volume of shell fragments. Good circulation
maintains the cxygen content , and the sand is relatively free of fine silt
and organic deposits (Trumble 1973).

Most investigators agree that adult sand lance are found primarily in shallow
water fairly close to land (Nikol'skii 1954, Kasahara 1961, North Pacific
Fur Seal Commission 1962). In the Bering Sea, sand lance have been found
to range from depths of O to 100 meters (Fedorov 1973a), but they are most
abundant above the 50 meter depth, at least in summer, according to Shuntov
(1963). Sand lance increase in importance in the diet of pelagic fur seals
with the proximity of the feeding seals to land (North Pacific Fur Seal
Commission 1962), suggesting that the fish may be more abundant or available
for capture in those areas. According to Clemens and Wilby (1961), they
abound along sandy beaches and offshore sand bars.

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Neither water temperature nor salinity are thought to appreciably restrict the distribution of Ammodytes. Sand lance are thought to be eurythermal as they have been collected from water varying in temperature from nearly 0°C to 20°C and above (Kasahara 1961, Trumble 1973). Inoue et al. (1967) even found sand lance aestivating in water over 24°C off the Japanese coast. They also found that young sand lance 5 cm or less in length are able to survive in salinities of 4.69 to 24.21°/oo.

Sand lance have been reported from the Bering Sea in Bristol Bay (Gilbert 1895, Baxter 1975), and in Harendeen and Izembek Bays on the north side of the Alaska Peninsula (Gilbert 1895, Wilimovsky 1964). They have also been found among the food items of pelagic fur seals collected in the Bering Sea (North Pacific Fur Seal Commission 1969). Wilimovsky (1964) reported that they inhabit the inshore waters of most of the islands of the Aleutian chain: Attu, Agattu, the Semichi Islands, Kiska, Amchitka, Tanaga, Adak, Great Sitkin, Igitkin, Atka, Umnak, Unalaska, the Krenitzin Islands, and Unimak. Sand lance have also been found among the stomach contents of fur seals captured in the Gulf of Alaska, with a high frequency of occurrence from seals taken near Kodiak Island (Trumble 1973). See also Figures in Section IV, Historical Data Record of Non-salmonid Pelagic Fishes, of this report.

LIFE HISTORY

Reproduction

According to Hamada (1966), sand lance ranging in age from one to three years participate in spawning activities in Japanese waters. The percentage of the total spawning population contributed by each age class varies some-what from year to year. One-year-old fish range from 20 to 77% of the spawners (average 54.7%) but, since older fish normally have a higher fecundity, 63 to 95% (average 76%) of the total number of eggs are spawned by two- and three-year-olds (Hamada 1966, 1967). Hamada (1967) considers the spawning population to have a one-to-one sex ratio.

The fecundity of sand lance from the Murman coast ranges from 3,300 to 22,000 eggs per female (average 6,800) for fish with standard lengths of 12 to 19.5 cm (Nikol'skii 1954, Trumble 1973). The smaller Japanese sand lance with lengths of 7 to 12 cm, have a fecundity of only 1,000 to 8,000 eggs per female (Trumble 1973). Spawning takes place at depths of 25 to 100 meters in areas having strong currents (Trumble 1973).

There is some uncertainty as to the time of year at which Ammodytes hexapterus spawns. Members of the sand lance family spawn in summer, fall, or winter, depending on the particular species and the location (Trumble 1973). According to Nikol'skii (1954), sand lance from the Murman coast spawn in winter, and Trumble (1973) feels that the same is true of sand lance in the northeast Pacific.

Sand lance appear to be able to tolerate a wide range of temperature on the spawning ground as observed by Kasahara (1961) in Japanese waters. The temperature ranged from 2 to 60C near Hokkaido and as high as 17 to 18 °C off Kyushu.

Inoue et al. (1967) examined the ovaries of mature fish and from the size and number of ova they concluded that sand lance spawn once or twice per season. The eggs, which are oval in shape and adhesive, are deposited in clumps of three to four on the sandy substrate (Nikol'skii 1954, Trumble 1973). The diameter of the mature eggs is reported as 0.72 to 0.97 mm in the U.S.S.R. (Nikol'skii 1954) and approximately 0.66 mm in Japan (Inoue et al. 1967).

Nutrition and Growth

Growth

Inoue et al. (1967) incubated artificially fertilized. sand lance eggs at 15.74°C and 6.19 °C and found that hatching took place within 13 and 33 days respectively. Upon hatching the yolk sac larvae were 3.81 mm in length. Under natural conditions, the pre-larva is demersal, burying itself in the sand until after the yolk sac is absorbed at a length of 4 to 5 mm, at which time the larva becomes planktonic (Trumble 1973). The Soviet Bering Sea expedition of 1958-59 caught larvae in the summer ichthyoplankton that ranged in length from 7.4 to 33.7 mm (Musienko 1963). Metamorphosis to the adult stage occurs at a length of 30 to 40 mm (Trumble 1973).

According to Trumble, the maximum period of growth is between January and August of each year, and most growth takes place during the first two years of life. Although sand lance are easily aged with otoliths, Table 111.21.1 seems

Table 111.21.1 .--Growth of the Pacific sand lance in the Murman Region, U.S.S.R. (from Nikol'skii 1954).

Age	0+	1+	2+	3-t
Length	9.5	11.6	13.5	15.9

to provide the only information on length-age relationships for the sand lance. Hart (1973) reports the maximum length of sand lance as being 20 cm (8 inches) off British Columbia and at least 26 cm (10.25 inches) in the Bering Sea. In contrast, Kobayashi (1961) found that sand lance in the southern part of the Bering Sea (50°-55°N) are larger than those in the central portion (55°-60°N) , which in turn are larger than those in the northern part of the Bering Sea (60°-65°N).

Food and feeding

Sand lance larvae feed on diatoms and dinoflagellates at first, but soon
change to a diet of copepod nauplii and copepods (Trumble 1973). Adults
consume copepods, Chaetognaths , and fish larvae near Japan (Inoue et al.
1967), and in the North Sea they eat amphipods and annelids (Trumble 1973).

Inoue et al. (1967) performed laboratory feeding experiments on sand lance
720 to 740 mm in length. They discovered that the preferred feeding times
were in the morning and in the evening, and each specimen could consume
approximately 20,000 copepods per day.

Large pelagic feeding schools have been observed in the ocean during the
day, but some sand lance with full stomachs have been taken in bottom trawls
(Trumble 1973). While this might indicate that part of the population stays
near the bottom to feed, it may also mean that sand lance return to the
bottom to rest and digest their food after feeding in the surface layers.
Benthic invertebrates do occur in the diet, but not very frequently (Nikol'skii
1954). Sand lance apparently feed during all seasons of the year (Trumble
1973) .

Predators and Competitors

The sand lance is an important food item in the diet of many fish, marine
mamma ls, and birds. Sand lance larvae have been found to make up 50% of
the spring diet of herring in the North Sea (Trumble 1973). Juveniles of
sockeye and silver salmon in the Bristol Bay region were found to have sand
lance larvae in their stomach contents, making up 5.2% and 38.9% of the
total food items by weight , respectively (Straty and Jaenicke 1971). Adult
sand lance are used as forage by cod, chinook and coho salmon, halibut,
ling cod, and many other fish (Bean 1889, Hart 1973). Andriyashev (1937)
reported that cod in the south part of the Anadyr Gulf feed solely on sand
lance, and Outram and Haegele (1972) observed that 26% of 1,196 Pacific
hake taken off British Columbia had sand lance in their stomachs.

Sand lance appear to be an important food item of fur seals, although their
percentage of the diet seems to vary widely. Fur seals captured at certain
times and locations, both in the Gulf of Alaska and in the Bering Sea. have
no more than trace amounts of sand lance in their stomachs (Taylor, Fujinaga,
and Wilke 1955; Wilke and Kenyon 1957; Marine Mammal Biological Laboratory
1970). In 1960, however, sand lance composed 37% of the stomach contents
of the pelagic fur seals sampled in Alaska , and was thus ranked among the
leading food items (North Pacific Fur Seal Commission 1962). Stomachs of
seals captured south of Unimak Pass in May 1962 contained sand lance 52%
by volume (Fiscus, Baines, and Wilke 1964). Another sand lance feeding ground
appears to be near Kodiak Island, because fur seals collected on Portlock
Bank were observed to be feeding primarily on sand lance (North Pacific
Fur Seal Commission 1971). Soviet investigators have reported finding sand
lance composing 35.8% of the volume of the stomach contents of Bering Sea
fur seals (North Pacific Fur Seal Commission 1969) and also finding sand
lance among the food of the bearded seal (Geptner et al. 1976).

Although the various species of sand lance have similar food habits, possible competition is reduced because they occupy different habitats (Trumble 1973). Inoue et al. (1967) found, however, that competition may exist between sand lance and Chaetognaths, at least in Japanese waters. Both sand lance and Chaetognaths feed on copepods, and the number of Chaetognaths was reduced where large populations of sand lance were found.

Parasites

Arai (1969) compiled a list of the known parasites of sand lance:

Digenea: Galactosomum sp. (larval)
                   Lecithaster gibbosus
Monogenea: Gyrodactyloidea
Cestoda: Phyllobothrium sp. (larval)
Nematoda: Anisakis sp. (larval)
Acanthocephala: Echinorhynchus gadi Mueller 1776
Copepods: Lepeophtheirus sp.

Inoue et al. (1967) report that a nematode infests the body cavities of sand lance off Japan. The number of fish seems to vary with the habitat of the host, and as many as 93 have been found in a single specimen.

Behavior--Schooling and Migrations

Sand lance are known to form pelagic feeding schools at least during the day (Trumble 1973), and sometimes large schools have been seen swimming against the tidal currents in channels (Hart 1973). At night, sand lance are thought to rest on the bottom, but attraction by moonlight or artificial light may bring them to the surface (Trumble 1973). Although Kasahara (1961) concluded that sand lance do not migrate long distances, in some areas sand lance approach the coast for spawning, then return to deeper water after the spawning season is over (Trumble 1973).

POPULATION STRUCTURE AND DYNAMICS

Length frequency distribution of Bering Sea sand lance are given in Table 111.21.2, and from this one can infer that fish in the southern part of the Bering Sea are generally larger than those found further north (Kobayashi 1961).

Sand lance are assumed to have a one-to-one sex ratio, but the age composition, at least that of exploited populations, tends to vary greatly from year to year (Inoue et al. 1967).

Although many investigators have commented on the large numbers of sand lance found in Alaskan waters (Bean 1887, 1889; Scheffer 1959; Trumble 1973), very little quantitative and qualitative information is available. Analysis of fur seal stomach contents provides some indications of the availability of large populations of sand lance, at least in inshore areas near the Alaska Peninsula and Kodiak Island (Fiscus et al. 1964; North Pacific Fur Seal Commission 1969, 1971; Trumble 1973).

Table 111.21.2.--Length-frequency distribution of Bering Sea sand lance (from Kobayashi 1961).

Range (mm)	Bering Sea												Tots)
	June				July				August				
	50°~55°N	55°~60°N	0°~65°N	Total	0°~55°N	55°~60°N	0°~65°N	Total	50°~55°N	55°~60°N	30°~65°N	Tots	
11~15	1			1	2	17		19					20
16-20	0			0	1	142		143		.			143
21-25	5			5	2	152		154			1	1	160
26-30	43			43	6	251		237			14	14	294
31~35	73		.	73	14	96		110			9	9	192
36-40	84			84	32	47		79	1	.		1	164
41-45	36			36	71	5		76	17			17	129
.46-50	7			7	32			32	13			13	52
51~55					3			3	9			9	12
56~60									5			5	5
61-65									3			3	3
Total (n)	249			249	163	690		853	48		24	72	1174
Mean value (M)	35.40			35.40	41.13	26.00		28.85	48.90		29.65	42.55	31.10
Standard deviation (a)	5.55			6.55	6.65	6.25		8.65	6.2.5		2.75	9.50	8.15
Sampling error $\left(m = \dfrac{\sigma}{\sqrt{n}} \right)$	0.2.5			0.35	0.52	0.23		0.29	0.99		0.55	1.12	0.23

FI SHING

At present, there are intensive commercial fisheries for sand lance in Europe and Japan which began during the 1950's (Trumble 1973). The Japanese landings show a wide variation in annual catch ranging from 40,000 to 110,000 metric tons during the period 1953 to 1963 (Inoue et al. 1967). In 1968, the total world catch of sand lance reached 350,000 metric tons (T-rumble 1973). No fishery at present exists in the northeast Pacific.

The Japanese sand lance fishery uses a variety of small set nets, lift nets, seines, and attracting lights, but the hoop net, a type of lift net, is the most important gear (Inoue et al. 1967). The European fishery, on the other hand, uses mainly midwater trawls and purse seines (Trumble 1973).

POTENTIAL CONTRIBUTION TO DOMESTIC AND INTERNATIONAL ECONOMY

Sand lance not only are valuable as forage and bait for commercially important species, but they have recently become a target themselves for commercial fisheries in Europe and Japan (Bean 1887, 1889; Trumble 1973). In Europe sand lance is substituted for herring in the production of fish meal and oil, but in Japan it is boiled or dried and used for human consumption (Trumble 1973). Scheffer (1959) reported that they are delicious when rolled in corn-meal or cracker crumbs and fried in butter. Thus, should substantial sand lance populations be found to exist in Alaskan waters as is believed, they may someday support a sizeable fishery.

CHUB MACKEREL (Scomber japonicus)
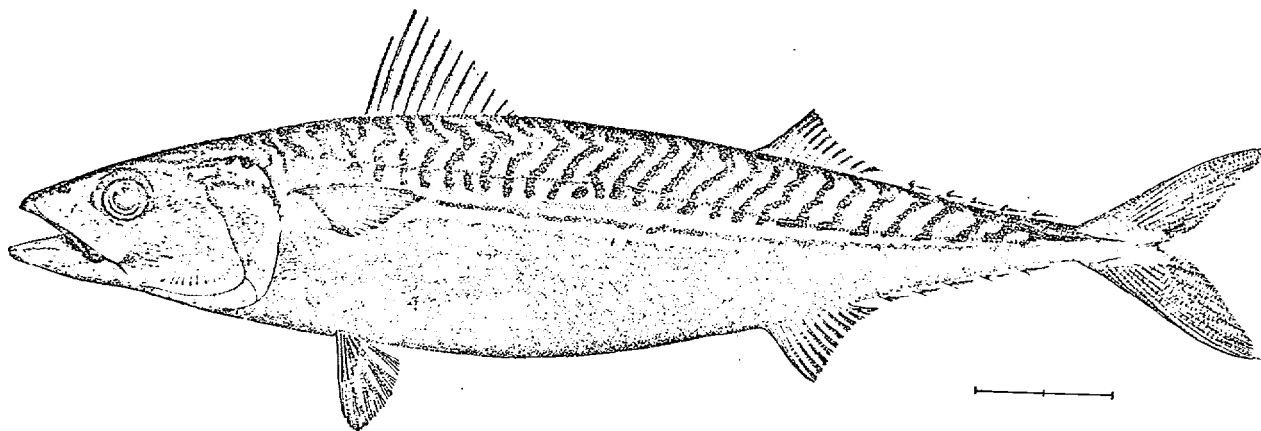
Figure 111.22.1.--Chub mackerel, Scomber japonicus (from Brice et al. 1898).

IDENTIFICATION

The scientific name, Scomber japonicus, is now the accepted name which replaces others used in the past including Pneumatophorus japonicus, Scomber diego, and Pneumatophorus diego. The preferred common name is chub mackerel (Bailey et al. 1970), although, Pacific mackerel is used officially by the state of California (Kramer 1969). Other names include American mackerel, striped mackerel, greenback mackerel, blue mackerel, zebra mackerel, and right mackerel.

Some taxonomists divide the genus into at least two genera with a worldwide distribution because some mackerel have, and others do not have, an air bladder, as well as other morphological and ecological distribution differences (Kasahara 1961). In the Pacific Ocean, however, they are all placed in the same genus (Hart 1973).

In a racial study by Roedel (1952), specimens from British Columbia, California, Soledad Eay, Sebastian Vizcaino Eay, and general area around Cape San Lucas and the Gulf of California were examined.. Statistical analyses of four morphological characteristics indicated the California and British Columbia samples were the same 'out the samples from the other areas were different. Returns from tagging studies showed that some mackerel tagged near Vizcaino Bay reached California fishing areas.

DISTRIBUTION

The biological range of the chub mackerel exceeds its economic range. They have been reported in the eastern Pacific Ocean as far north as Prince William Sound in Alaska (Rounsefell and Dahlgren 1934) and to Eanderas Bay and Mazatlan, Mexico, on the south (Hart 1973). In Asian waters, they are found along the coast of the U.S.S.R., Sakhalin, Japan, Kwantung, and as far south as Taiwan (Hart 1973).

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In some years, the chub mackerel is fairly abundant off the coasts of British Columbia, Washington, and Oregon. It is most commonly found along the coast of California from Point Conception south into the Gulf of California and as far offshore as 370 km (Kramer 1969).

There is no record of chub mackerel from the Bering Sea. Except for the single report from Prince William Sound in 1932, the literature has referred only to the occurrence of mackerel in southeastern Alaska (Rounsefell and Dahlgren 1934, Wilimovsky 1954). Hart (1973) mentions their being fairly abundant, in some years, along the west coast of Vancouver Island, and they formerly mixed in with schools of pilchard. Specific reference is made to an occurrence in Prince Rupert Harbor.

The available information indicates the chub mackerel are found, in some years, within the areas of concern to this report as occasional transients. The distribution is limited in part by water temperature. Kasahara (1961) reported that mackerel are found mostly in waters where the temperature ranges from 10° to 20°C.

Danilova (1971) stated that the Russians sent exploratory fishing vessels to Baja California in 1964-1966. They found the largest concentrations of mackerel in February through April 1966 between lat 23°18' to 24°08'N and lat 26°30'N. They were found only in the coastal zone and were absent 50-100 miles from shore. Commercial concentrations were found in 1964-1965 at depths of 3-60 m. Most were taken at depths of 3-15 m at the dark time of the day. The range of surface temperatures was 21.8°-23.5°C.

LIFE HISTORY

Reproduction

The "chub mackerel spawns from March to October, but mostly in April through August (Knaggs and Parrish 1973). Spawning is in waters close to the coast, mostly in waters of the continental shelf (Kasahara 1961). Apparently the eggs mature in successive batches within a season. Approximately 500,000 eggs may be produced according to Walford (1937). The eggs are about 1.06 to 1.14 mm in diameter (Kramer 1960), are spherical and pelagic, and they hatch in about three days (Fry 1936). Roedel (1949) stated that, although eggs usually were in waters less than 100 fathoms, they were found in waters up to several hundreds of fathoms in depth but never were found beyond the 1,000 fathom line. His data indicated that mackerel usually spawn fairly close to shore in surface waters having a temperature range of 59-75°F (15°-23.9°C).

Ahlstrom (1956) reported that no eggs or larvae were taken north of Point Conception. Some spawning occurs off southern California and northern Baja California, but the bulk is off central and southern Baja California and in the Gulf of California. The distribution resembles that of the Pacific sardine. Spawning occurs in March through July off southern California and northern Baja California, and throughout the year off central Baja California, according to Ahlstrom. The abundance of eggs and larvae varies yearly.

According to to Knaggs and Parrish (1973) , no chub mackerel spawn in their
first year (O group); 22.5% mature at age I, 65.7% at age II, 75.1% at age
III, 84.7% at age IV, 84.2% at age V , and 87% at age VI and older. Knaggs
and Parrish also found indications that males mature earlier than females
and that females do not necessarily spawn every season.

In the western Pacific Ocean, Gorbunova (1965) reported the number of eggs
varying from 344,000 upward to over 2,600,000. Major spawning areas extend
from the Yellow and East China Seas to the west coast of Hokkaido (Kasahara
1961). In these areas spawning occurs from April through July and occurs
early in the season in the south and late in the north. Spawning also occurs
on the east coast of Japan in early April to June cr July. Observed surface
temperatures during spawning ranged from 13.5°C to 21°C. Observed lengths
for the different age groups were: I, 13-22 cm; II, 27-32 cm; III, 32-37 cm;
and IV, 36.5-41.0 cm. The oldest observed mackerel were 10 years old.

Kasahara further noted that wintering temperatures were 9°-16°C or higher
and that mackerel tend to live in middle and bottom layers shallower than
20C m, possibly due to the temperatures. and lack of food in the upper waters.
Spawning was accompanied by a northward migration as the temperature increased.
Small quantities of mackerel were found at depths to 100-200 m in summer.
Salinities varied from 31.7 to 34.7°/00.

Nutrition and Growth

Nutrition

Fry (1936) reported the Pacific mackerel as having tremendous appetites,
eating virtually anything that can be swallowed, including copepods, schizo-
pods, anchovies, and squid. They were also prone to feeding on only one
food at a time. Walford (1937) stated they ate small fish, squid, shrimp,
copepods, isopods, kelp, and even garbage items such as a piece of onion
or orange cn rare occasions.

Fitch (1956b) found that larvae and juvenile fish were the most important
food items in the 228 stomachs he examined. O'Connell and Zweifel (1972),
in laboratory studies, found that mackerel tended to select only the larger
foods such as euphausiids when feeding on plankton.

Growth

Chub mackerel grow very rapidly in the first few months after hatching (Fry
1936). Walford (1937) reported average lengths at the end of the first,
second, third, and fourth years as 11¼ in. (33.7 cm.), 14.25 in. (36.2 cm)
and 15 in. (38.1 cm). They reach lengths up to 20 inches and an age of 7
to 10 years (Fry 1936).

Predators and Competitors

Chub mackerel were included in the food in the stomachs of sperm whale taken in Japanese waters (Mizue 1951, cited by Berzin 1971), and they were found in the Dan porpoise in Japanese waters (Wilke and Nicholson 1958). Chub mackerel were found in the stomachs of seals in California, Washington, Oregon, and in Alaskan waters between latitudes of about 54°N and 60°N in 1958 and 1960 in the eastern Pacific Ocean, and they were prominent food items of fur seals in Japanese and Russian waters in several years of investigations (North Pacific Fur Seal Commission 1962, 1975).

Behavior

Tagging experiments in 1935-1943 by the California Division of Fish and Game showed that chub mackerel from as far north as Oregon and as far south as the central portion of lower California eventually entered the southern California fishery (Fry and Roedel 1949). No evidence of cyclic movements was detected. There were evidences of a slow dispersion over a period of years from the place of tagging. Kramer and Smith (1970c) noted that the e work reviewed by Fry and Roedel and cooperative tagging by the Fisheries Research Board of Canada off the Columbia River showed an interchange throughout the region and that all regions contributed to the southern California area.

Chub mackerel school by size according to Kramer (1960). In the western Pacific Ocean, Kaganovskii (1955) noted that mackerel schooled only in the daylight hours and near dusk. This behavior made it possible to locate the schools with aircraft. In addition, birds tended to collect in areas where herring and anchovies were in schools. Red jelly fish and ctenophores were observed at temperatures of 8° to 9°C. When the jellyfish and ctenophores disappeared, herring appeared and they in turn were followed by mackerel in 2 to 4 days.

POPULATION STRUCTURE AND DYNAMICS

Frey (1971) reported that otoliths were reliable for determining the age of Pacific mackerel less than 6 to 7 years old. The oldest mackerel found, among 25,000 examined, appeared to be in its twelfth year. Frey reported mackerel. grow to 10 inches (25.9 cm) in the first year of life and that generally about 50% spawn at age two and 100% after age three.

Kasahara (1961) indicated that fluctuations in catch may be due more to variations in recruitment than to fishing. Frey (1971) also stated that mackerel are subject to year-class strength. In 1968, for example, a good year-class was produced, but it was grossly affected by jack mackerel fishing which caught large numbers of chub mackerel incidentally. Apparently there were seven poor year-classes in a row which produced poor fishing in 1962 through 1968.

Frey estimated the spawning biomass in 1963 was 80,000 tons but it was not replaced, the current estimate being 5,000 tons. In poor years after 1941, the spawning biomass was estimated at 60,000 to 100,000 tons. Kramer and Smith (1970c) quoted Blunt and Parrish to the effect that the spawning biomass was less than 5,000 tons off California in 1969 and that detrimental environmental factors existed that prevented good recruitment.

Analyzing the tagging work by Fry and Roedel (1949), Fitch (1952) found the mortality rate for chub mackerel was between 74 and 78% per year for the 1940-1941 and 1942-1943 fishing seasons. Age studies by Fitch indicated a mortality rate of 48% between the second and third year, 62% between the third and fourth year and 70% between the fourth and fifth year.

FISHING

Prior to 1928, the chub mackerel was used as a fresh fish and the fishery was of little significance. The development of a canning process revolutionized the fishery, however. Handlines which had once supplied the market were replaced by lampara nets in the 1930's, then by purse seiners. In the period 1939-1947, scoop net boats dominated, using ground bait as chum to attract the fish.

The catch reached a peak of nearly 150 million pounds in 1935 (Frey 1971). Thereafter, the trend was generally down to a low in 1953, an increase until 1957, then a fairly steady decline to new lows in 1967, 1968, and 1969. Sports fishermen still take thousands of fish each year.

Fitch (1952) pointed out that as time went on, larger boats used purse lines in place of cork lines, then steel cables, and then chain on the lead lines. These changes, along with the increased use of depth sounders and radio telephones increased fishing efficiency. At times, the fisheries for jack mackerel and sardines take substantial numbers of chub mackerel that are in the same area.

The changes in catches resulted in a number of fishing regulations. The effectiveness of the regulations in restoring the fishery to higher levels of abundance has not been demonstrated.

The Japanese fishery is intensive, the proportion of older fish in the catch has declined and mackerel are no longer caught in the more northern waters (Kasahara 1961).

POTENTIAL CONTRIBUTION TO DOMESTIC AND INTERNATIONAL ECONOMY

Although review of the literature indicates the chub mackerel appears north of Oregon only very rarely, the historical catch data show its occurrence may not be so infrequent in the Gulf of Alaska (see Section IV, Historical Data Record of Non-Salmonid Pelagic Fishes, of this report). Perhaps further exploratory fishing with appropriate gear may result in data showing whether commercial quantities are available.

ALBACORE (_Thunnus alalunga_)
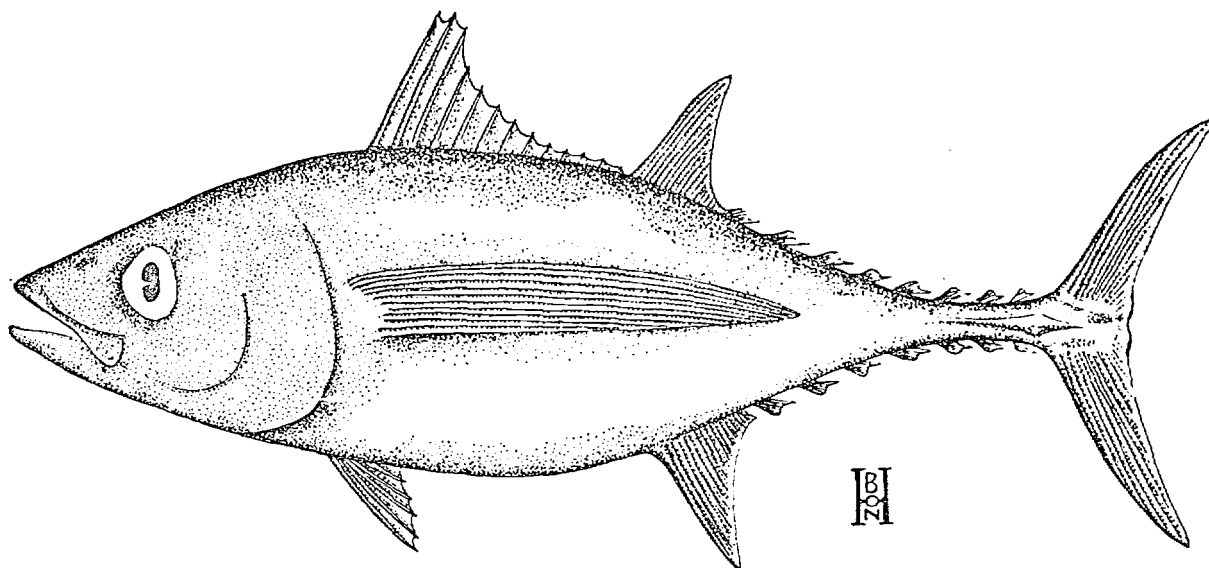
Figure 111.23,1.--Albacore, _Thunnus alalunga_ (from Hart 1973).

DESCRIPTION

The commonly accepted scientific name is _Thunnus alalunga_, although at one time the name _Germo alalunga_ was used, Today the tunas and mackerels of the world are included in the family _Scombridae_, but some taxonomists have put the tunas in the Thunnidae and the mackerels in the Scombridae. Although the common name albacore is almost universal, it is sometimes called longfinned tuna or simply tuna.

No evidence of subspecies has been found in the Pacific Ocean area.

DISTRIBUTION

General Distribution

Albacore are world-wide in distribution, occurring in the North and South Pacific Oceans, the Indian Ocean, and the North and South Atlantic Oceans (Brock 1959) (Figure 111.23.2). Along the North American coast it ranges from the Gulf of Alaska to Baja California (Yoshida and Otsu 1963). Little is known about the distribution of eggs and larvae, but the few locations at which larvae have been collected are predominantly in the equatorial region between 10° North and South latitudes, according to Yoshida and Otsu.
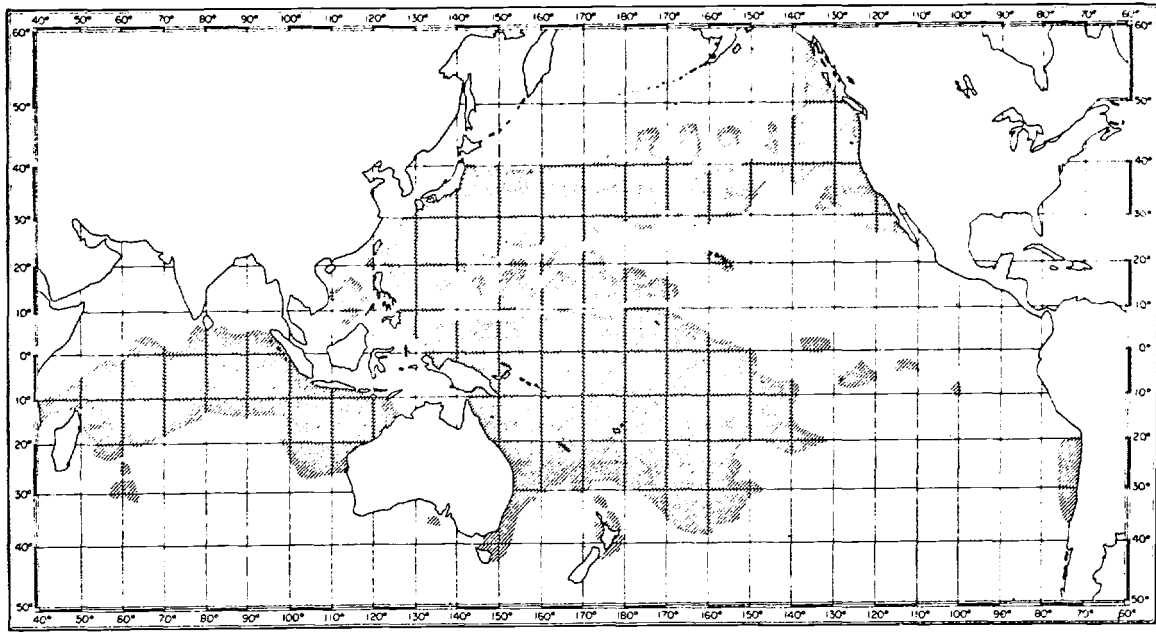
Figure 111.23.2. Distribution of albacore in the Pacific and Indian Oceans (redrawn by Yoshida and Otsu 1963 from Brock 1959).

Occurrence in the Gulf of Alaska

Albacore seem to be only occasional visitors to the Gulf of Alaska, although rumors of their presence in Alaskan waters have occurred regularly since the mid-1920's (Powell and Hildebrand 1950). Most of the rumors, when investigated, have proved to be false and were based on sightings of porpoises or fish species new to local inhabitants. Occasionally, however, when surface waters are warmer than normal, albacore are found further north than usual. Thus, in 1948, quantities were found off Graham Island (Queen Charlotte Islands) and in Dixon Entrance in the first week of September, but they had vanished by the second week (Pacific Fisherman 1949). Again when the waters of the Gulf of Alaska warmed to some extent, small quantities of albacore were taken by trollers on their way across the Gulf of Alaska in 1958 (Pacific Fisherman 1958), and they were caught by vessels fishing out of Kodiak in 1959 (Browning 1974).

The appearance of albacore is seasonal, as depicted by the distribution maps in Fig. 111.23.3 which were prepared from data collected during the INPFC salmon gill netting surveys. According to Neave and Hanavan (1960), no albacore were taken in the Gulf of Alaska until after the middle of July in the years 1956 and 1957, and it was not until August of those years that they were taken as far north as 50°N. lat. Similarly, it was late August in 1939 when a halibut vessel encountered a school of albacore at lat 52°40'N, long 134°20'W (Samson 1940). On August 30, 1949, several large albacore were taken at lat 55°10'N and long 140°2'W, although these fish were apparently scattered, not schooled.

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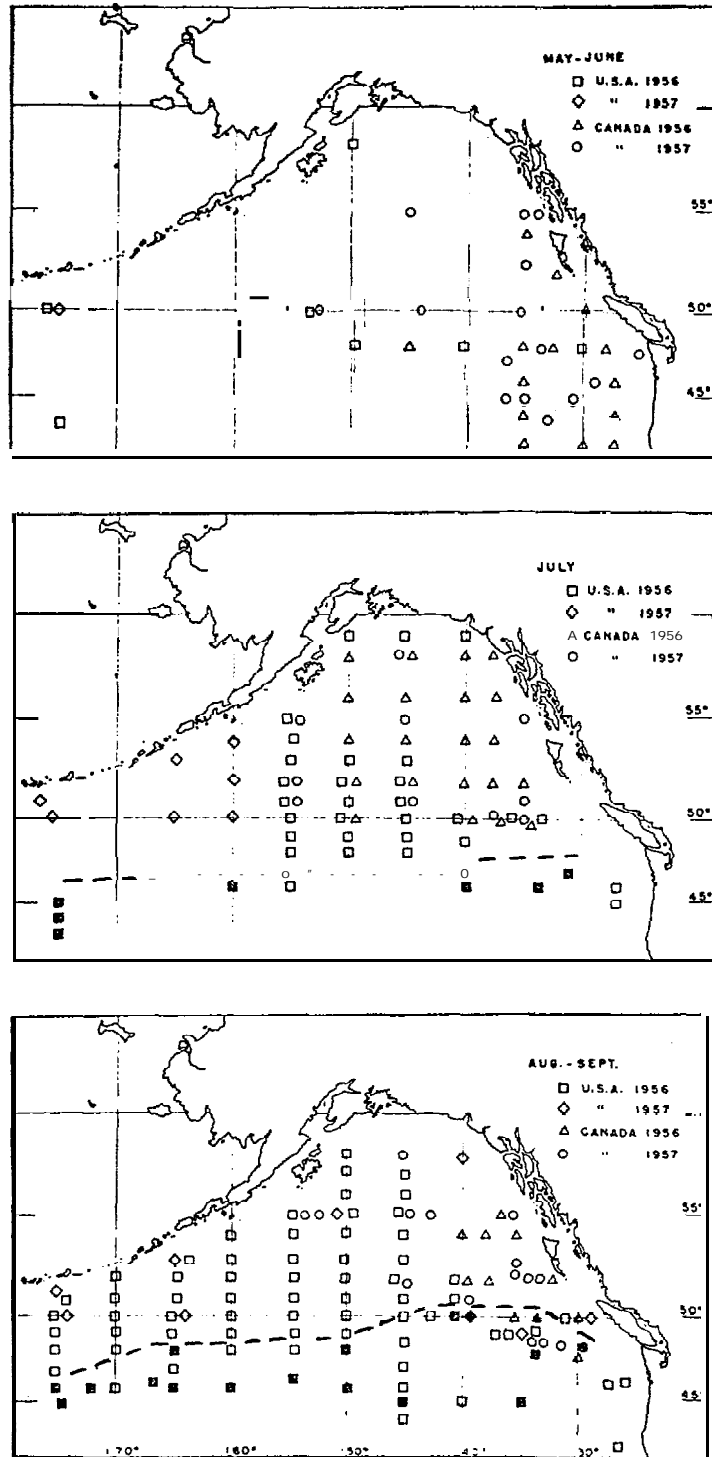
Figure 111.23.3. --Distribution of albacore in gillnet catches in the Gulf of-Alaska, 1956-57. The broken line represents-the approximate northern limit of the catch records. (Black symbols indicate occurrences, open symbols indicate where albacore were not taken.) (From Neave and Hanavan 1960).

Many investigators have suggested that water temperature is a primary factor affecting the migratory habits of albacore. Indeed, there seems to be a high correlation between the average landings in Oregon and Washington and the average August surface water temperature for the ocean between 40 and 50°N latitude (see Fig. III. 23.4). Table 111.23.1 summarizes the surface water temperature range at which most albacore catches occur in the northeast Pacific Ocean.
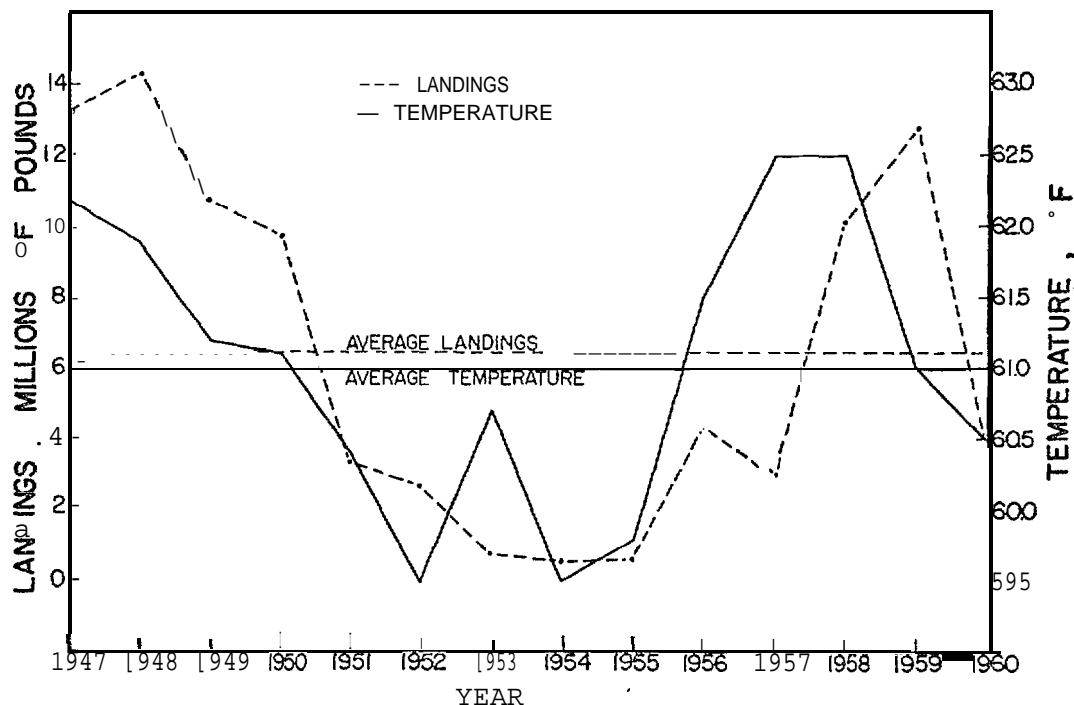
Figure 111.23.4.--Average sea surface temperatures for August for the oceanic area from 40° to 50° N. latitude and from the west coast of North America to 130° W. longitude for the years 1947 to 1960, and total landings of albacore in Oregon and Washington for the same years (from Johnson 1962).

A considerable amount of effort has been expended in attempts to predict the temporal and spatial distribution of albacore in the northeast Pacific. Lane (1965) felt an understanding of the effect of winds on ocean circulation may be of some benefit in determining when favorable conditions may occur. During the summer and early fall, when albacore are more likely to be migrating north-ward, the direction of the prevailing winds might influence the proximity of albacore to the coastline. If the winds are predominantly northerly during this period, the surface waters near the coast are transported offshore and are replaced by an upwelling of cooler water from below. The tuna, tending to stay in the warmer water are displaced offshore where they are not as available to the fishery. On the other hand, when the prevailing winds are souther-ly, both the warmer water and the albacore are found closer to the coast.

Table 111.23.1 .--Surface water temperatures for albacore catches, best fishing tempera-
tures, and water color reported in areas of best fishing in the northeastern Pacific
Ocean (modified from Alverson 1961).

Authors	Year	Temperature ranges				Thermocline depth, best catches		Water color, best catches
		Occurrence		Good catches				
		°F	"C	°F	°C	feet	meters	
Bethune 1948	1947	59-70	15-21.1	63-65	17.2-18.3	-		
Scagel 1949	1948	56.8-63	13.8-17.2	58-60	14.4-15.5	-		
Powell arid Hildebrand 1950	1949	56.8-61	13.8-16.1	58-61	14.4-16.1	50	15.2	blue
Partlo 1950	1949	57-62	13.9-16.7	58-60	14.4-15.5	50-75	15.2-22.9	-
Powell, Alverson, and Livingston 1952	1950	54-62	12.2-16.7	57-61	13.9-16.1	60	18.3	blue
Partlo 1951	1950	56-67	13.3-19.4	59-61	15-16.1	-		
Schaefers 1952	1951	58-62	14.4-16.7	58-61	14.4-16.1	.		
Schaefers 1953	1952	54-61	12.2-16.1	58-62	14.4-16.7	-		
Powell 1957	1956	55-63	12.8-17.2	5 8	14.4	50-75	15.2-22.9	-
Lane 1965	1962	58.1-60.4	14.5-15.8	-				
Lane 1965	1963	55.4-57.9	13.0-14.4	-				

As Alverson (1961) pointed out, however, temperature does not appear to be the only determining factor of tuna distribution. While waters with a surface temperature of 14.4°C (58°F) or less are not likely to yield commercial quantities of albacore, surface water temperatures above that value do not necessarily insure a successful albacore fishery. He felt that distribution within a region of suitable temperature may be dependent on a variety of factors such as the location and abundance of forage fish. Probably the stage in their migration cycle is also very important (Lane 1965), for albacore tend to appear in waters of the northeast Pacific only in August or September even if periods of favorable water temperature have occurred earlier in the summer. The depth of the thermocline may also be a limiting factor (Alverson 1961), because some evidence suggests that albacore inhabit only the layer of water above the thermocline.

Fishermen have long noted some correlation between water color and good albacore catches. Powell, Alverson, and Livingstone (1952) found that blue oceanic water is generally warmer than the green coastal water rich in particulate matter such as plankton. They reported,' however, that while tuna spend most of their time in the warmer blue water, the best fishing is, often where the two water masses meet, implying that albacore may cross into the colder water for brief periods to feed on forage more abundant there.

LIFE HISTORY

Reproduction

Because albacore spawn in oceanic rather than coastal waters (Yoshida and Otsu 1963), relatively little is known about this portion of their life history. In addition, because of difficulties in determining the age of albacore, investigators differ in their estimates of the age at which the albacore reaches sexual maturity. According to Clemens (1961), some albacore reach maturity at the age of four years and a fork length of 85 cm., but most do not reproduce until they are five years old and at least 93 cm. in length. Using a growth curve he constructed, however, Otsu (1960) determined that the age of a mature 90 cm. fish would be seven to eight years.

Fecundity estimates are complicated by a difficulty in obtaining albacore with mature eggs and by a lack of knowledge of the frequency of spawning. Otsu and Uchida (1959a) found remnants of eggs among ripening eggs in an ovary, implying that albacore may spawn at least twice during a spawning season. Assuming that most of the eggs in the ovaries are released in a single spawning, however, a fecundity range of 800,000 to 2,600,000 eggs per female is estimated (Yoshida and Otsu 1963).

Many investigators are in agreement that the albacore caught off the coasts of Oregon, Washington, British Columbia, and Alaska are immature fish and that adult fish spawn elsewhere (Partlo 1955b, Otsu and Uchida 1959a, Clemens 1962). Otsu and Uchida (1959a) found albacore with fully developed eggs near the Hawaiian Islands in summer. From their investigations, they felt that the spawning area might encompass a broad area of the Pacific, including those areas under the influence of the North Equatorial Current as far east as the Hawaiian Islands. Clemens (1962) also felt that the spawning grounds covered an area 2,000 miles or more in length in the equatorial region, but that most of the spawning took place in the spring between March and May.

Although the spawning behavior of albacore has not been observed, they are thought to spawn in groups without specific sexual partners (Yoshida and Otsu 1963). Fertilization is external and is thought to occur at deep water levels (Clemens 1962, Yoshida and Otsu 1963).

The most deveLoped albacore ovarian eggs that have been measured were 0.8 to 1 mm. in diameter (Otsu and Uchida 1959a). pelagic eggs found in the Mediterranean and though to be those of albacore, were between 0.84 and 0.94 mm. in diameter, globular, and transparent (Yoshida and Otsu 1963).

Growth and Nutrition

Growth

Various methods have been employed in the determination of the age of albacore, which is important in the establishment of the rate of growth. Ages have been estimated from scales, vertebral sections, length-frequency distributions, and from tag-recovery data with differing results. Because there is some question whether the first ring on vertebral sections or scales actually represents an annulus, differing growth curves can in some cases be made to agree by adding or subtracting a year from the interpreted ages (Shomura 1966). Perhaps the most reliable results to date have been obtained from recoveries of tagged fish, despite the fact that they are necessarily based on few specimens, Figure 111.23.5 illustrates the curves obtained by two different investigators from 21 (Clemens 1961) and 11 (Otsu and Uchida 1963) recoveries. The curves are strikingly similar, and a shift of one year in the assigned ages would make them agree closely (Shomura 1966).
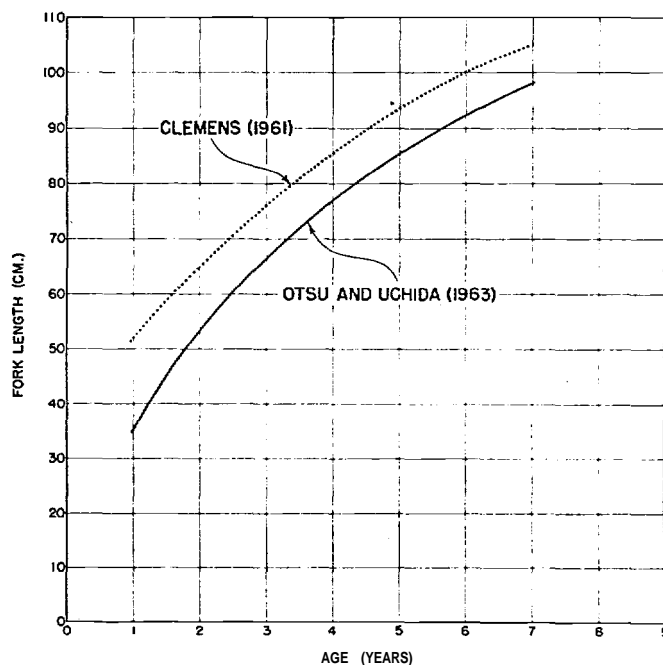
Figure 111.23.5. --Growth of albacore estimated from tag-recovery data (from Shomura 1966).

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A weight--length relationship based on 1,073 specimens by Clemens (1961) is presented in Fig. 111.23.6.

Neither Brock (1943) nor Clemens (1961) found any significant difference in growth of male and female albacore, but Otsu and Uchida (1959b) found some evidence suggesting a faster growth rate among large males.

Fork Length (Inches)

Fork Length (Millimeters)
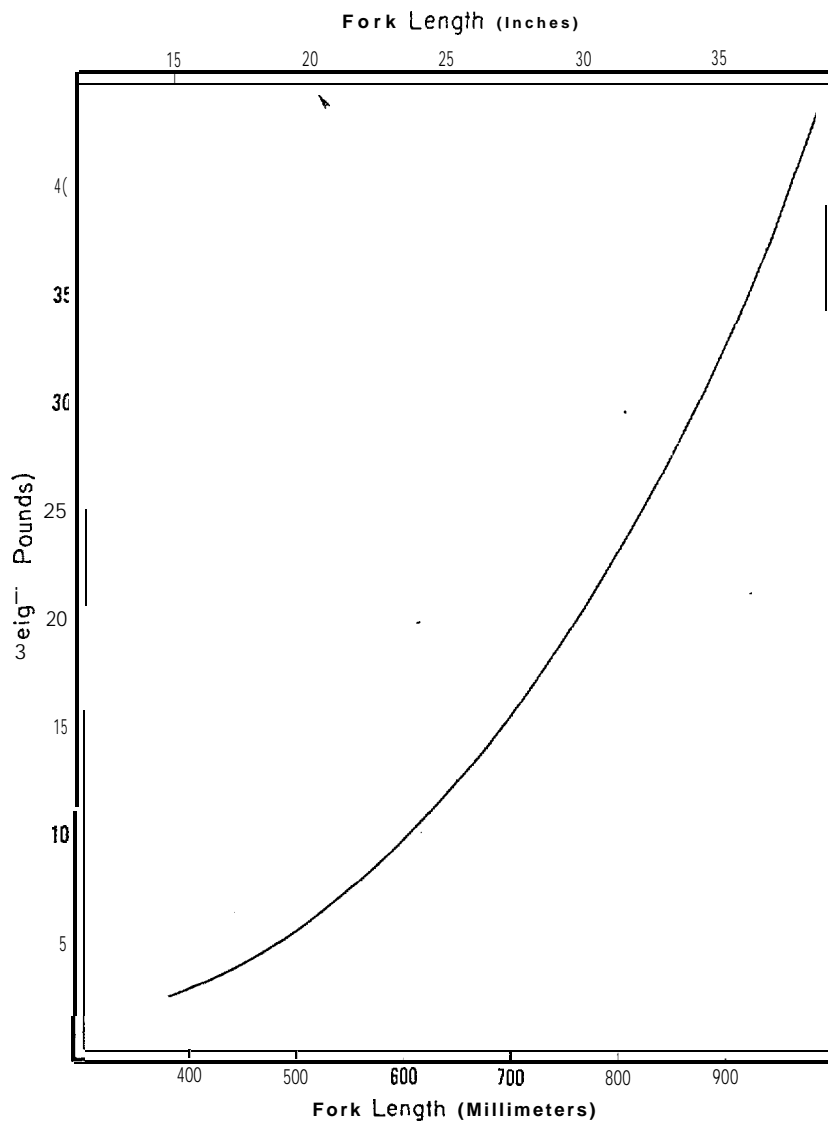
Figure 111.23.6 .--Albacore weight-length relationship based upon 1,073 fish landed in the North Pacific in 1952, 1955, and 1960. $W = 4.936 \times 10^{-8} L^{2.99}$ (from Clemens 1961).

According to a number of investigators, albacore in the northeast Pacific feed predominantly on fish such as pilchard, lantern fish, saury, anchovies, and juvenile rockfish and invertebrates such as squid (Hart and Barraclough 1948, Partlo 1950, Powell et al. 1952, Iverson 1971).

After examining the stomachs of 348 albacore captured by long-lining, trolling, and gill net fishing in the central and northeast Pacific, Iversen (1962) reported an observed difference in stomach content of albacore caught by the various gears. Figure 111.23.7 illustrates the disparity in composition percentages, but also emphasizes the importance of fish and squid to the albacore diet. Pearcy (1973) found that the stomach contents of albacore caught within 130 miles of the Oregon coast were mostly fish while squid and euphausids predominated in those of tuna caught further offshore. Other fish occasionally found in albacore stomachs include lanternfish, barracudina (Iverson 1971); small mackerel, herring, young albacore (Walford 1937); black cod, wolf eel, juvenile flatfish, snailfish (Powell et al. 1952); and ragfish (Pearcy 1973). Occasionally ingested invertebrates include euphausiids, the shrimp Sergestes similis, octopus (Iverson 1971), and jellyfish (Powell et al. 1952).
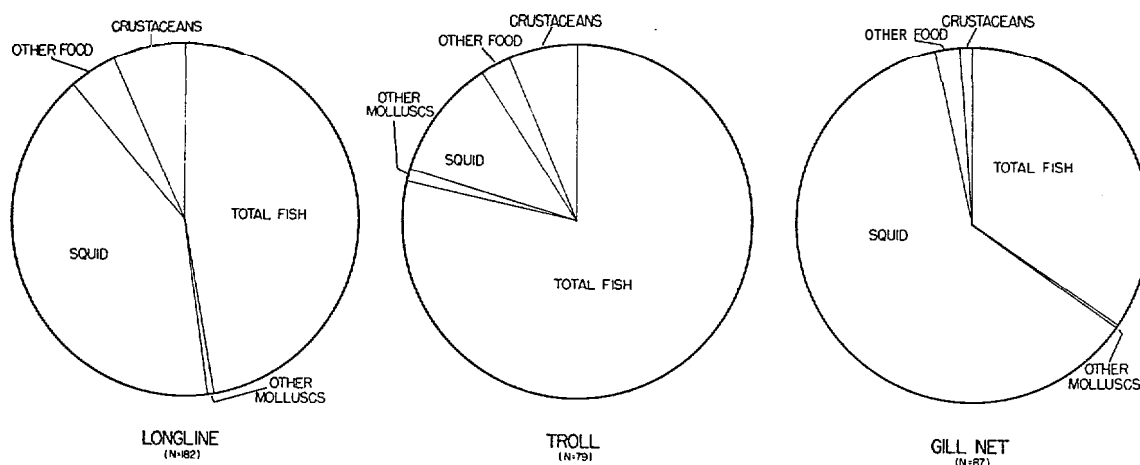
Figure 111. 23.7 .--Comparative importance, by volume, of major food elements found in 348 albacore stomachs, according to method of capture (from Iversen 1962).

Many fishermen claim that albacore feed only at certain times of the day, as evidenced by "morning and evening bites" (Pearcy, Panshin, and Keene 1975), and consequently they found fishing was better at these times. While Clemens (1961) reported that early season catches off California were made throughout the day, he noted that later in the season to the north, best catches were made in the morning and late afternoon. In contrast, Pearcy et al. found no evidence supporting a morning and evening feeding. They felt, however, that the pursuit of a food item such as saury which exhibits diel variations in depth might cause albacore to move from the surface layers to deeper water

where they are less likely to be caught. Depth of feeding also seems to vary somewhat with latitude, according to Clemens (1961). He found that albacore in the southern feeding grounds mainly fed near the surface while further north they consumed smaller percentages of surface-dwelling organisms.

Predators and Competitors

Known predators of young albacore include black marlin, striped marlin, short-nosed spearfish, yellowfin tuna, and adult albacore (Yabe et al. 1958; Kishinouye 1923 cited by Yoshida and Otsu 1963). Although large scombrids are thought to have few enemies, dolphins, killer whales, swordfish, and sharks are known to attack them on occasion (Yoshida and Otsu 1963).

Competition for food in the equatorial Pacific is thought to occur between albacore, yellowfin tuna, and bigeye tuna (Iversen 1962).

Parasites

Table 111.23.2 lists known parasites of Pacific ocean albacore and the part of the fish each one infests.

Table 111.23.2.--Parasites of albacore (from Yoshida and Otsu 1963).

Parasite	Location of infestation	Reference
Elythrophora brachyptera	Inner surface of operculum	Yamaguti (1936)
Hirudinella spinulosa	Stomach	Yamaguti (1938)
Didymocystis alalongae	Gill arch	" "
Didymocystis opercularis	Operculum	" "
Platocystis alalongae	On skin	" "
Melanematobothrium guernei	In sub-maxillary muscle	" "
Anisakis sp.	------	Yamaguti (1941)
Contracaecum legendrei	Stomach	" "

Behavior--Schooling and Migrations

Length-frequency studies have indicated that albacore tend to school by size (Brock 1943). They also exhibit differing depth preferences according to age. The younger, smaller fish travel mainly in the surface waters while the schools of older, larger individuals frequent somewhat deeper waters (Clemens 1961).

Rothschild and Yong (1970) pointed out that albacore must move continuously in order to maintain gill aeration because they lack muscles to pump water over the gills. Tagging studies have proven that these tunas are capable of traveling vast distances, and the work of a number of investigators has revealed a pattern to their movements. Figure 111.23.8 illustrates one concept of albacore migrations which seems to agree with most of the biological observations made to date, such as albacore age and time of appearance in an area, the peak season of catch by the various fisheries, the type of gear found most successful in an area, water temperatures and results of tagging studies. This model, as explained by Otsu (1960), is based on the concept of there being a single population of albacore in the North Pacific which is exploited by the Americans off the west coast of North America during the summer and fall, by the Japanese in the central Pacific in the winter, and
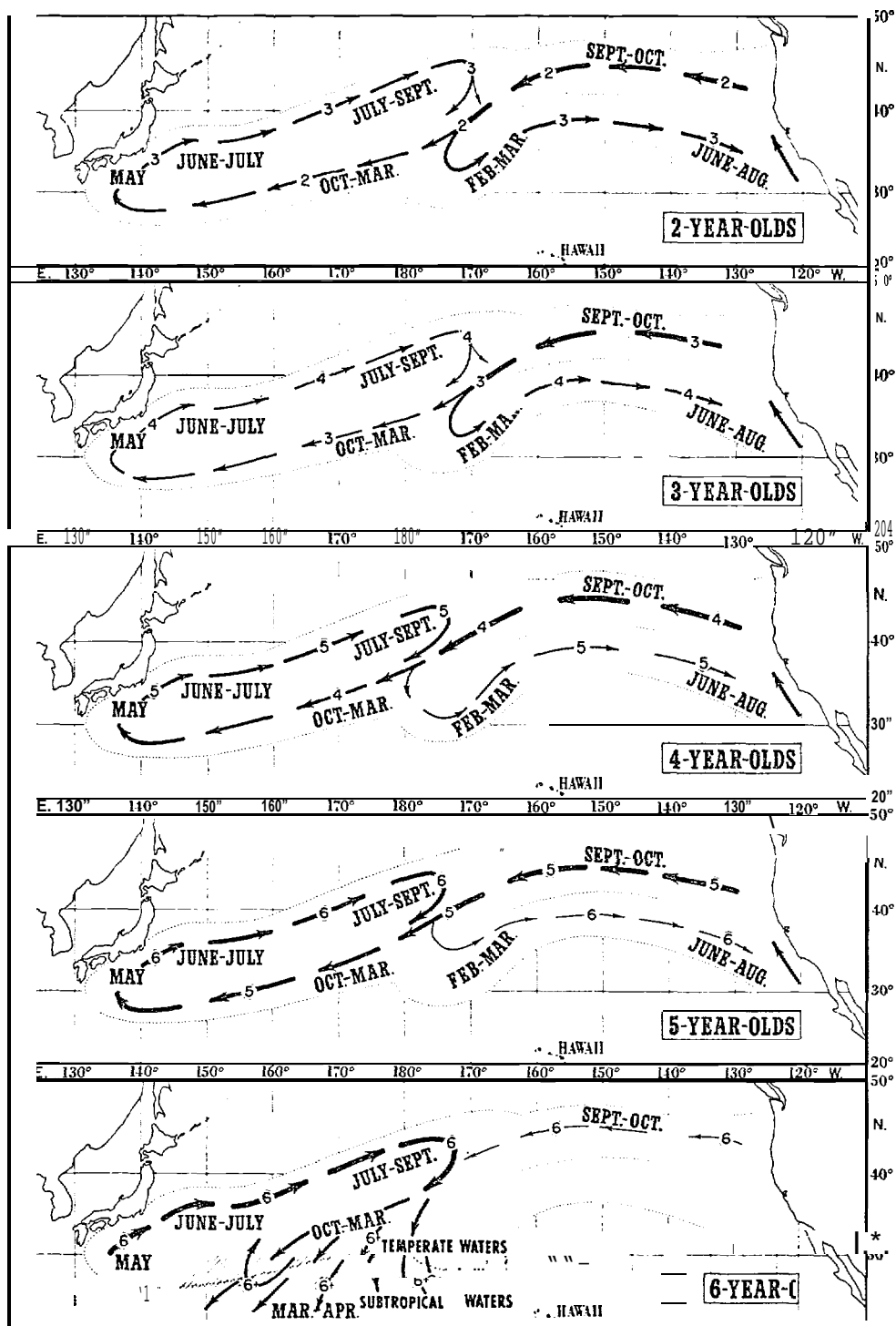
Figure 111.23.8. --Model of albacore migrations in the North Pacific
Ocean, by age groups (ages encircled). (Modified by Rothschild and Yong
1970 from Fig. 9 of Otsu and Uchida 1963).

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by the Japanese in the western Pacific in the spring and summer. This assumes that albacore are capable of making transoceanic migrations (as confirmed by tagging) but does not require that they make the full crossing each year. The model also indicates a differing migration pattern for the different age classes. As the albacore age, more of them migrate across the ocean to the western Pacific and fewer return to the eastern Pacific. This is in agreement with the observation that the Japanese fisheries tend to take larger fish than the American fisheries (Clemens *1962)*. Sexually mature fish are not normally taken by either fishery, and Otsu and Uchida (1959a) speculate that they cease their transpacific movements and migrate instead in a north-south direction in mid-Pacific, moving in deep water to and from spawning grounds.

POPULATION STRUCTURE AND DYNAMICS

In general, the sex-ratio of albacore in the Pacific Ocean has been found to be nearly 1:1, although a few departures from this ratio have been found (Yoshida and Otsu 1963). Brock (1943) noted a greater percentage of males than females among Oregon albacore less than 67 cm. in length. He attributed this discrepancy, however, to difficulties in sexing the small fish. Otsu and Uchida (1959a) discovered that males predominated among the larger fish captured near the Hawaiian islands. A later paper by the same authors (1959b) noted that this ratio may reflect a differential growth rate by sex among the larger albacore.

Length-frequency studies (Brock 1943; Hart and Pike 1948; Hart 1949; Partlo 1950, 1955a) noted the presence of several length-classes in the North American fishery, ranging from one to four separate groups which were thought to represent age classes. Partlo (1955a), who found four separate peaks (at 53, 63, 67, and 71 cm.) in a length frequency distribution of albacore caught off Oregon and California, tentatively assigned the corresponding length groups ages of 3,4,5, and 6 years. He noted, however, that the first vertebral ring was not very clear, and if discounted, would reduce the ages of the length classes by one year. Such a reduction would make these data match what would be expected from the albacore migration model proposed by Otsu and Uchida (1963).

FISHING

Albacore fishing in the western United States started to become commercially important as early as 1885 and was the first important west coast tuna fishery. The fishery developed through the years as a California operation until the first commercial landings were made in Oregon in 1936 (Pacific Fisherman 1936). The first landings in Washington were made in 1937 followed by landings in British Columbia in 1939 (Graham 1959). British Columbia landings were of little significance until 1948 when some two million pounds were Landed. The first commercial catches is Alaska were made in 1948 when about 400,000 pounds were landed (Pacific Fisherman 1948), but the fish were caught off the Queen Charlotte Islands.

United States landings of albacore taken off Oregon and Washington are still of substantial value every year, not only from commercial fishing but from recreational fishing by party boats and individual fishermen. Landings in British Columbia and Alaska may also have substantial value, although the

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actual catches may have been made south of Alaska or British Columbia. For example, boats from British Columbia have caught albacore from as far south as Mexico (Larkin and Ricker 1964).

The early fishery was a bait boat fishery using hooks and lines (Browning 1974). Seine boats were tried and still operate, although they take only a small percentage of the catch. Today most albacore are caught by trollers traveling at speeds of 8 to 10 miles per hour and using feathered jigs as lures. However, a few bait boats still operate, taking some 10% of the catch (Clemens 1961).

Fishing for albacore typically starts in June when they first appear off Mexico and southern California. These southern fisheries develop rapidly in July, peak in August and decline through the period September to January. Fishing in these areas tends to be 30 to 50 miles off the coast with most being caught 50 to 150 miles offshore (Browning 1974). As the season progresses, the larger albacore leave the southern areas first (Partlo 1950), and as the fish migrate further north, so does the fishery.

Movements of albacore up the coast are erratic and the migration paths are not fixed (Clemens 1961). Migrations shift and the more frequent and violent storms occurring in more northern areas may be partly responsible for the great fluctuations in catches in these areas. Albacore tend to follow desirable food as well as temperatures, and changes in food location may also influence both distribution and catches (Clemens 1961).

In some years albacore reach the waters of British Columbia and Alaska (Clemens 1961). In these northern areas, fishing may reach a peak in August or September then decline as the fish disappear to the west, the smaller ones tending to leave first (Partlo 1950).

POTENTIAL CONTRIBUTION TO DOMESTIC AND INTERNATIONAL ECONOMY

Although the albacore is rarely found in the southern part of the Gulf of Alaska, occasionally surface waters warm sufficiently to bring commercial quantities of the fish into the area, and they are available as targets-of-opportunity to fishermen fishing primarily for other species. Unless water temperature regimes should be altered or populations of albacore were to be found consistently in colder waters than at present, the chances of sufficient stocks being available to support a specific commercial albacore fishery in the Gulf of Alaska appear to be negligible.

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ATKA MACKEREL (Pleurogrammus monopterygius)
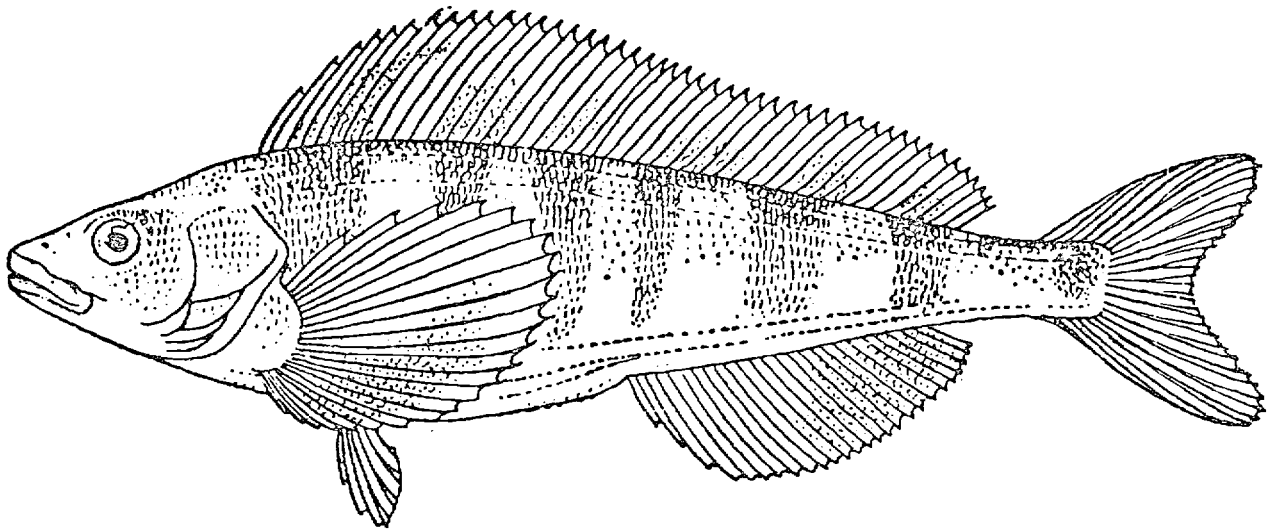
Figure 111.24.1.—Atka mackerel, Pleurogrammus monopterygius
(from Berg et al. 1949).

IDENTIFICATION

The Atka mackerel was originally described by Pallas in 1810 as
Labrax monopterygius but was redesignated in 1861 as Pleurogrammus
monopterygius, which is its presently accepted scientific name (Bean
1887). It has been known by a variety of common names, among them
Atka mackerel, Atka fish, yeLlowfish, striped fish, kelp fish, Spanish
mackerel, horse mackerel, and Alaskan mackerel (Turner 1886; Bean
1887, 1889). In Japan it is called hokke or yubi-ainame while in
Russia it is known as odnoperyĭ terpug, morskoĭ lenok, morskoĭ okun',
and sudachok (Berg et al. 1949, Okada and Kobayashi 1968).

A member of the greenling family (Hexagrammidae), Atka mackerel
has a somewhat perch-like appearance. Although the coloration is
extremely variable depending on the specimen and the time of year,
mature fish generally have five broad vertical stripes of dark olive
to black across the body. The dorsal part of the body is usually
olive and the spaces between the dark bands can vary from dingy
grey to lemon yellow to reddish orange (Rutenberg 1962). At the
peak of spawning, according to Andriyashev (1954), the stripes of
mature males become more distinct and the belly assumes a bright
lemon-yellow coloration.

Although Wilimovsky (1954) reports the range of Pleurogrammus monopterygius
as being from the Bering Sea to California, the Atka mackerel inhabits
mainly the southern part of the Bering Sea, the northern part of the
North Pacific Ocean, and the Gulf of Alaska (see Fig. 111.24.2). On
the Asian side of the Pacific, it is found off the northern Kurile
Islands; the south, west, and east coasts of Kamchatka; the Commander
Islands; Olyutorskii Bay; to Cape Navarin and the Gulf of Anadyr in
the north (Andriyashev 1954, Rutenberg 1962, Musienko 1970). Atka mackerel
frequent the whole length of the Aleutian chain from Attu to Unimak
and are occasionally found off the Pribilof Islands, the Alaskan Peninsula,
the Shumagins, and as far east as Kodiak according to Andriyashev (1954).
Larkins (1964) indicates that they are fairly common in both the northern
and southern portions of the Gulf of Alaska. Single specimens have
been found as far north as Providence Bay on the Chukotsk Peninsula
(Andriyashev 1954) and as far south as off the Monterey Peninsula in
California (Rutenberg 1962).
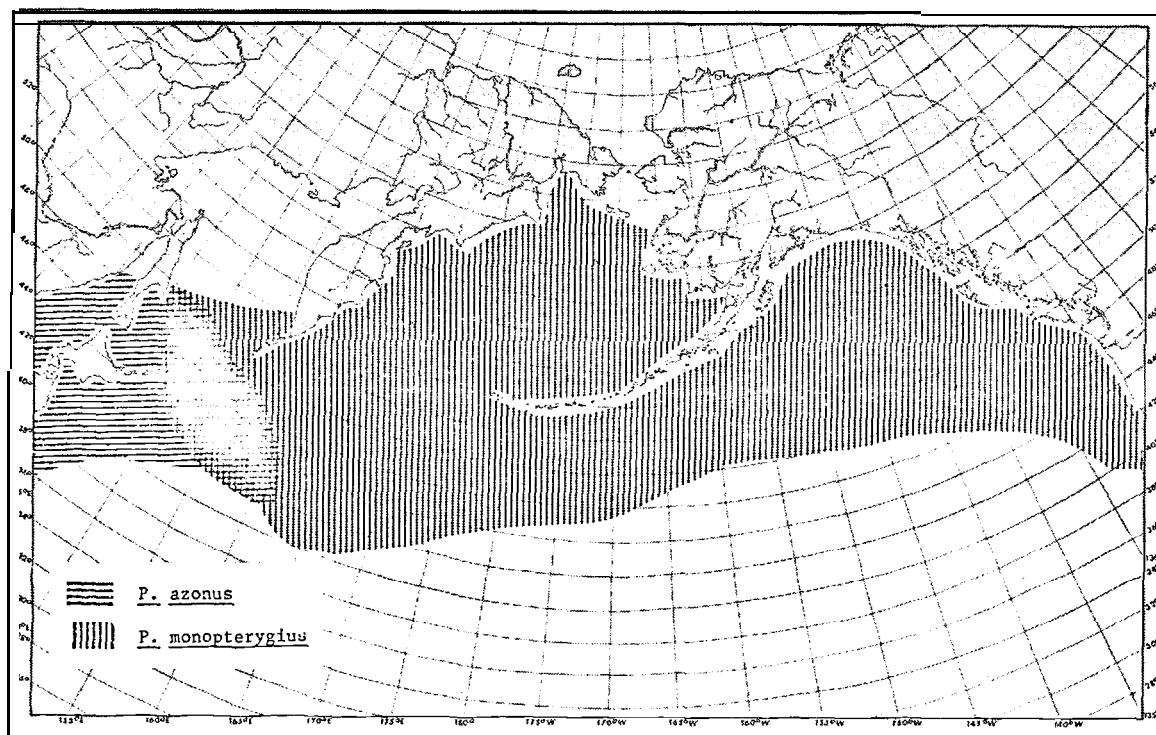
Figure 111.24.2 .--Presumed range of Pleurogrammus monopterygius and
  P. azonus in the North Pacific and Bering Sea. Both species are
  found further inshore than the map indicates (from information
  given in Andriyashev 1954; Rass, Kaganovskii, and Klumov 1955;
  Rutenberg 1962; Gorbunova 1962; and in Section IV of this report).

A related species, <u>Pleurogrammus azonus,</u> is sometimes confused with
<u>P. monopterygius.</u> This species is sometimes found off the southern
Kurile Islands and the southern coast of Sakhalin, but it has a center
of abundance in the Sea of Japan and off the coasts of Korea. Although
there may be some overlap on the edges of the ranges because the larvae
of both species are pelagic, Gorbunova (1962) considers the adults
to be geographically separated.

Historical distribution

There are indications (Rutenberg 1962) that the Hexagrammidae originated
on the western side of the Pacific Ocean and pelagic <u>Pleurogrammus
monopterygius</u> was able to spread eastward to the Aleutians. Although
it had been known to occur elsewhere in the Aleutians, the Atka mackerel
was first observed in great numbers off the island of Attu in 1875,
its appearance coinciding with the disappearance of the sea lion, <u>Eumetopias
stelleri,</u> (Turner 1886). Wilcox (1895) observed that at that time the
Atka mackerel, while found in many places in Alaskan waters, was most
plentiful around Attu. The pass between Atka and Amlia Islands was
remarked by Turner (1886) as being a place where countless 'thousands
of the fish came in from the Pacific to spawn. At this time they were
also reported to be abundant at Kiska Island, between Atka (Atkha)
and Adak (Athákh), between Umnak (Unálga) and Unalaska (Unalashka),
and among the Shumagins according to Turner, yet Gilbert (1895) indicated
that the Atka mackerel was almost unknown at Unalaska at that time.

Specific Distribution in the Bering Sea and Gulf of Alaska

Following hatching, Atka mackerel larvae migrate out to the open ocean
(Figs. III.24.3, III.24.4), as indicated by the frequent presence of
25-30 mm larvae in stomachs of salmon caught in the open sea 150-500
miles from the coast (Gorbunova 1962). Kashkina (1970) noted the presence
of larvae of this species in the Bering Sea summer ichthyoplankton.
Some degree of diurnal vertical migration of larvae was noted by Musienko
(1970) in the Bering Sea, for he found the largest numbers in the surface
layer at night and at depths of 2 to 30 meters during the day. Experimental
collections off the eastern coast of Kamchatka and near the Commander
Islands revealed a large number of fry present in the upper water layers
in the winter (Rass 1955). Immature fish migrate to inshore waters
during the summer, then retreat to the open ocean in the fall (Meek
1916) .

Because of their spawning habits , adult Atka mackerel have a seasonal
difference in distribution. During the summer months usually from
May to October, they are found in inshore waters, especially along
the south shore of the Aleutian chain (Cobb 1906). Their time of appearance
on the spawning grounds varies slightly from year to year depending
on oceanic conditions and locality, but the peak of their abundance
is generally in June, July, and August. During their migration to the
spawning grounds they are particularly vulnerable to predation by fur
seals and sea lions, and their occurrence in fur seal stomachs (Fig.
111.24.5) gives some idea of their distribution at this time. In the
fall they return to the open ocean (Cobb 1907). The three most important
biological determinants of distribution of the greenings are, according
to Rutenberg (1962): food, predators, and parasites.
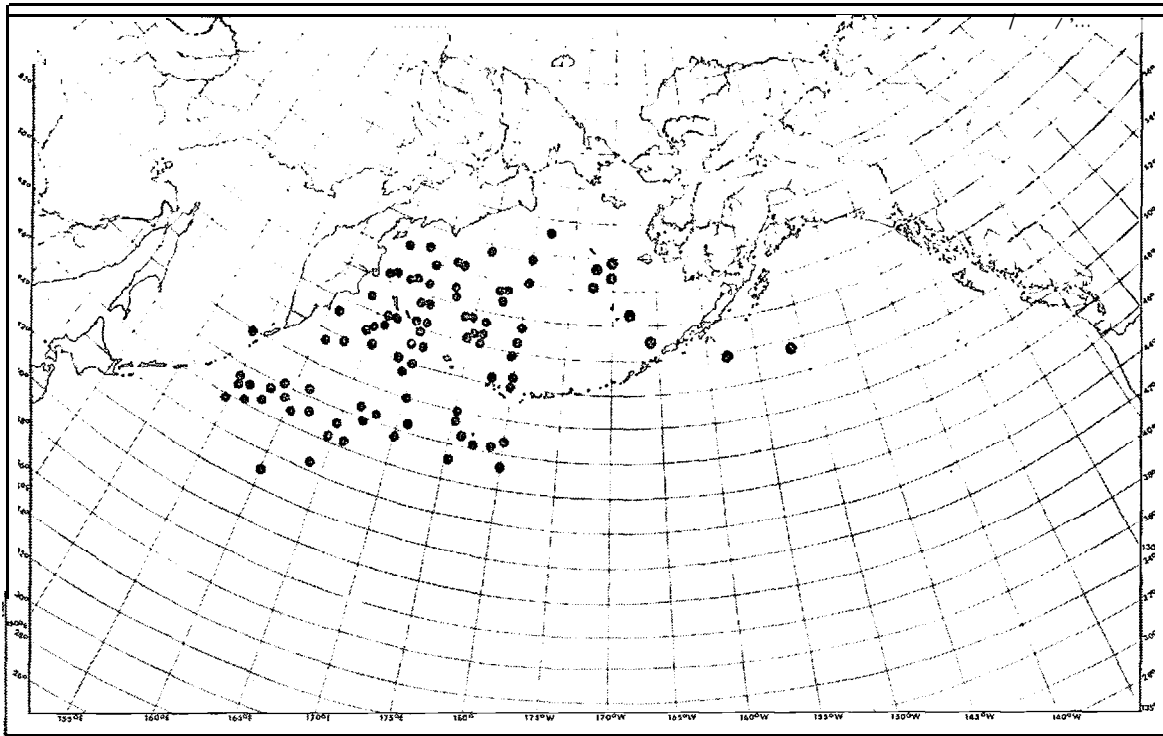
Figure 111.24.3.--Collection locations of Atka mackerel larvae in the
North Pacific Ocean and Bering Sea by Kobayashi, 1957-60, and by
Gorbunova (from Gorbunova 1962).
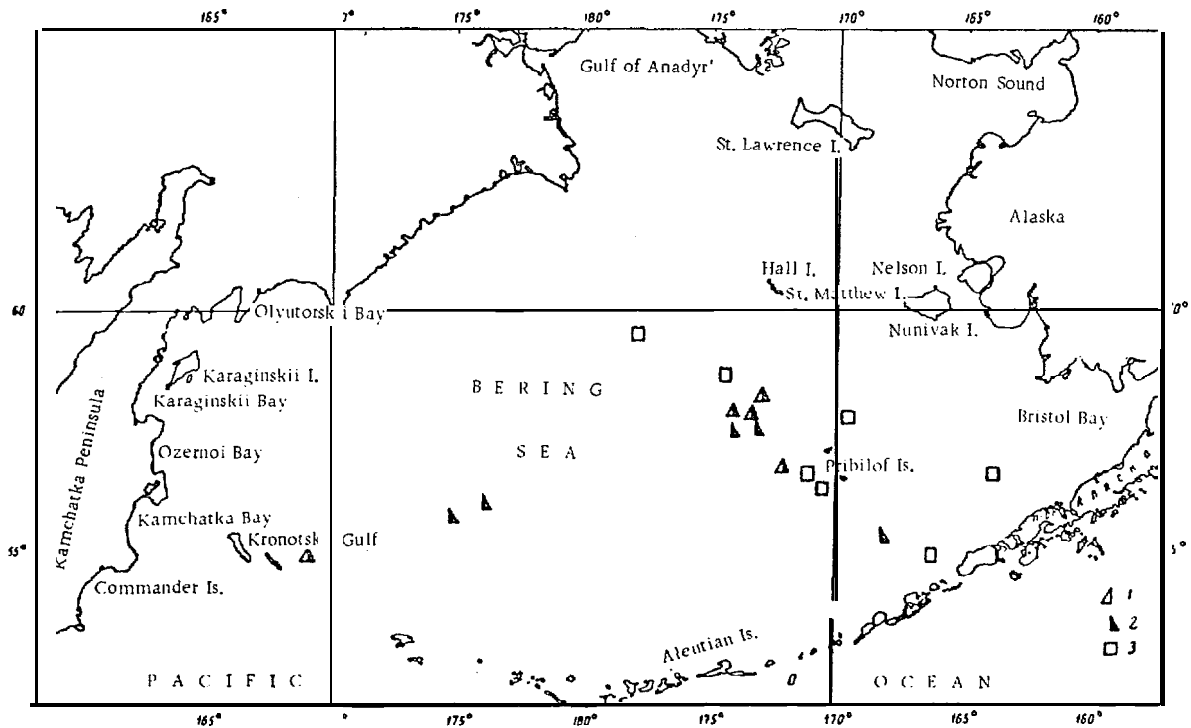
Figure 111.24.4.--Collection locations of Atka mackerel larvae and fry
in July-September 1958 (from Musienko 1963).

300

BERING SEA

PRIBILOF ISLANDS

100 FATHOM LINE

100

100

100

100

UNIMAK

NORTH PACIFIC OCEAN

100

100

AREA	OCCURRENCE PLEUROGRAMMUS MONOPTERYGIUS
WESTERN ALASKA	15
UNIMAK PASS	36
BERING SEA	27
TOTAL	79

60°

65°

170°

175°

55

0
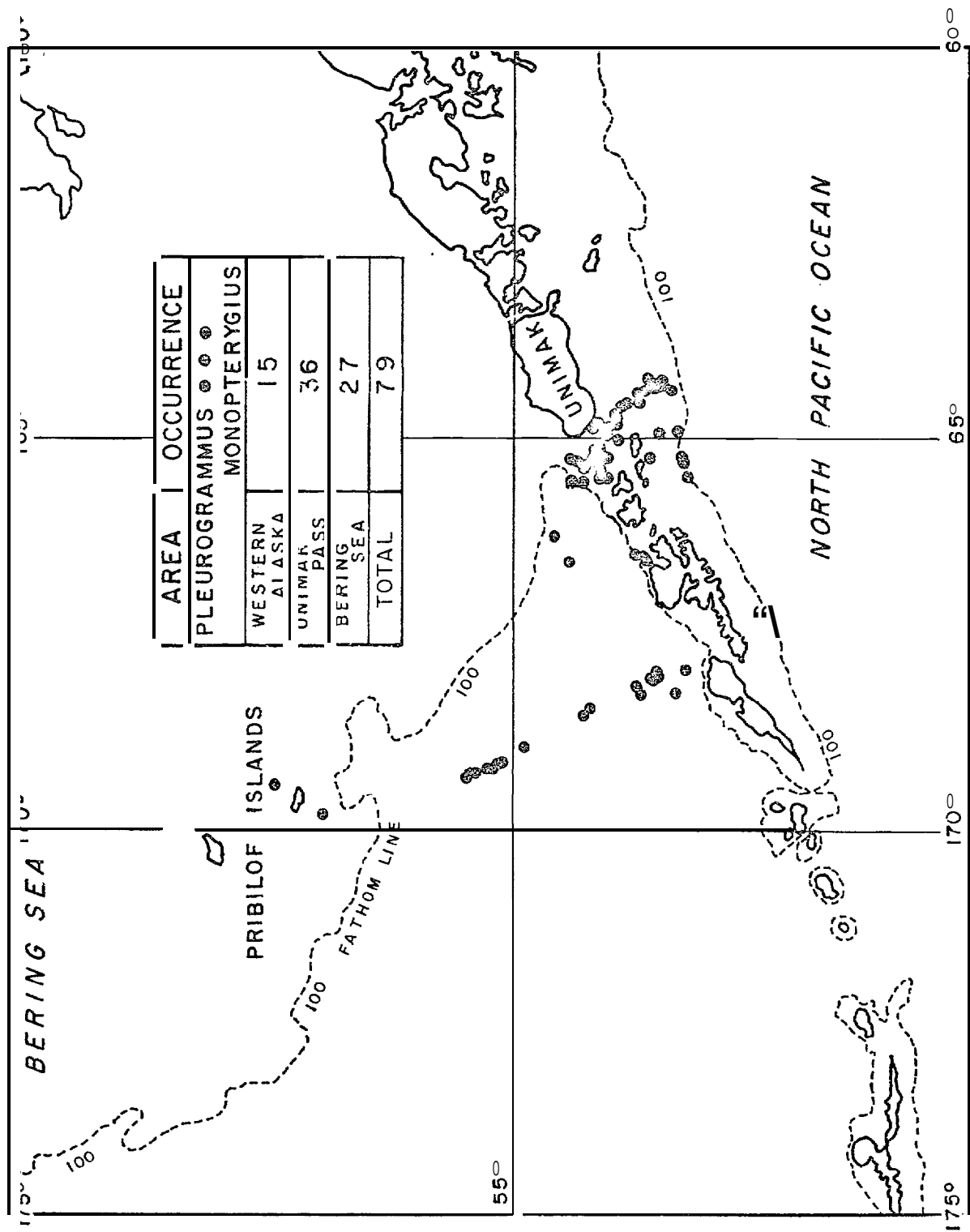
Figure III.24.5.--Locations where fur seal stomachs collected in 1962 contained Atka mackerel, Pleurogrammus monopterygius (From Fiscus, Baines, and Wilke 1964).

Reproduction"

<u>Pleurogrammus monopteryg</u>ius becomes sexually mature in the third or
fourth year at a length of approximately 33 to 35 cm (Gorbunova 1962).
Because the fish return annually to the spawning grounds, the spawning
schools are composed of fish from 3 to 11 years of age, although the
5+ and 6+ ages predominate. Sex ratios on the spawning grounds vary
according to date, the mature males appearing first; females and immature
males arrive a few days later (Meek 1916, Rutenberg 1962).

Spawning areas are located in the straits between islands, as in the
passes of the Aleutian, Shumagin, and Commander Islands (Turner 1886)
or in swift currents near promontories (Gorbunova 1962), but Rutenberg
(1962) reports that they also spawn in the Olyutorskii Gulf, and in
Avacha and Kronotskiy Bays. Four conditions seem to be important in
the selection of a suitable spawning site: current, bottom type, depth,
and bottom temperature (Gorbunova 1962). Various investigators have
noted the preference of Atka mackerel for spawning in an area of powerful
currents (Turner 1886, Gorbunova 1962, Rutenberg 1962). Possibly the
swift flow guarantees the aeration of the developing eggs according
to Rutenberg, who also states that generally the bottom is stony or
rocky and there are patches of <u>Laminaria</u> or other large seaweeds. According
to Gorbunova, the optimal depth appears to be 10 to 17 meters, because
at shallower depths the agitation of the surf seems to be detrimental
and at greater depths the bottom temperature is likely to be too low
(see Table 111.24.1). Spawning takes place at bottom temperatures from
5 to 8° C; laboratory incubation of eggs showed that temperatures below
3° C are unfavorable for development (Gorbunova 1962).

Table 111.24.1.--Water temperature in spawning areas of Atka
mackerel on the east coast of Kamchatka (from Gorbunova 1962).

Date	Depth (m)	Temperature 'C	
		At the surface	At the bottom
14-31 May	at the shore	1.4-2.8	---
2-20 June	" " "	4.0-6.0	---
1-30 July	6	8.6	7.0
	8	8.0	6.2
	12	8.5	8.2
	13	8.0	5-6.0
	14	9.5	5.3
	17	--	5.0
	35	10.5	3.2
1-20 August	11	---	7.2
	12	13.8	6.0-7.4
	14	11.4	7.3
	17	13.4	5.6
	20-30	--	2.5-3.0

The arrival of the Atka mackerel in the inshore areas varies somewhat
according to locality and seasonal conditions. Turner (1886) stated
that the first fish arrive in Attu around the 24th of April; off southeast
Kamchatka they appear in the second half of May (Medveditsyna 1962);
in Atka they come about the first of June according to Turner; and
in the Shumagins they approach in the latter part of August (Tanner
1890). As described by Turner, the configuration of the spawning shoals
at the height of spawning is a vertical layering with the immature
males and females uppermost, the prespawners in the second layer, and
the spawning fish below them. Often there is a fourth layer of. large
halibut feeding on the fish which venture too near the bottom.

There appears to be some disagreement concerning the type of substrate
upon which the eggs are laid. According to Turner (1886), Andriyashev
(1954), and Rutenberg (1962), the Atka mackerel deposits its sticky
eggs on the kelp, but Gorbunova (1962) and Musienko (1970) feel that
the egg masses do not adhere to the algal growth, and in fact the seaweeds
may impede the deposition of the eggs in the cracks between the stones
which they feel is the normal substrate.

Changes in the size composition of ovarian eggs of Pleurogrammus in
spawning areas off eastern Kamchatka (see Fig. 111,24.6), along with
observations of the spawning fish, indicate that three to four batches
of eggs are laid in a given spawning season , with an interval of five
to seven clays between each (Gorbunova 1962). The 'number of eggs laid
in each group varies directly with the size of the female, and may
vary with locality. The egg number in the first batch ranges between
1,656 and 12,185 and the total fecundity, that is, the total number
of eggs laid in any given spawning season, is between 5,324 and 42,815
eggs (Gorbunova 1962). Medveditsyna (1962) reported an average fecundity
of 9,000 eggs with a range of 4,500 to 20,000 eggs.

Atka mackerel eggs are demersal, they range in size from 2.50 to 2.79 mm
in diameter and have a sticky, thick brown membrane which enables them
to adhere to the substrate or to each other (Gorbunova 1962 Musienko
1970). The embryonic development illustrated in Fig. III.24.7 is described
in detail by Gorbunova.
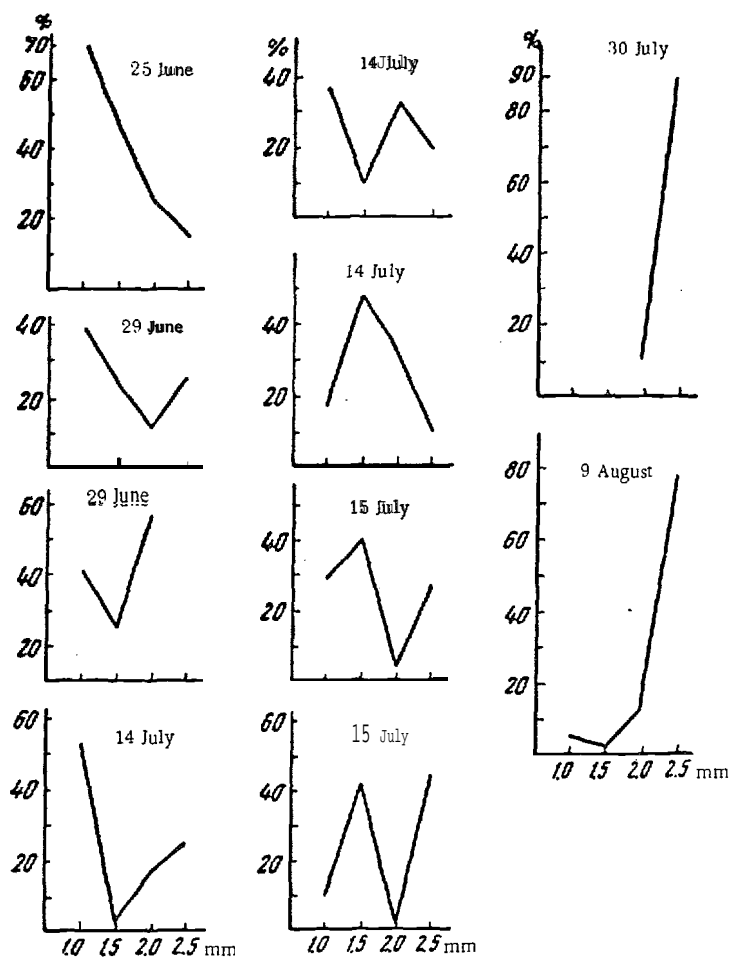
Figure 111.24.6.--Changes in the size composition of the ovarian
eggs of Atka mackerel during the spawning period off eastern
Kamchatka (from Gorbunova 1962).

After an incubation period of 40 to 45 days (Musienko 1970), the eggs
hatch into larvae approximately 10 mm in length which are immediately
able to feed on plankton (Gorbunova 1962). Figure 111.24.8 illustrates
the changes in morphology with the growth of the larvae and fingerlings,
and Table 111.24.2 gives their monthly size range. Gorbunova found
that there was no great difference in the rate of development between
the larvae near the Kurile Islands and those in the Bering Sea. Growth
rates do differ, however, between male and female Atka mackerel, the
females having a faster growth rate. Table 111.24.3, which gives the
age-length relationships of 144 specimens collected off southeastern
Kamchatka in the summer of 1958, illustrates this difference, and Fig.
111.24.9, giving the size composition of a spawning population, makes
this difference even more apparent. Adults can attain a length of 50
cm and a weight of 2 kg (Gorbunova 1962, Medveditsyna 1962), but specimens
of from 0.4 to 1.0 kg are more common in experimental catches off Kamchatka.
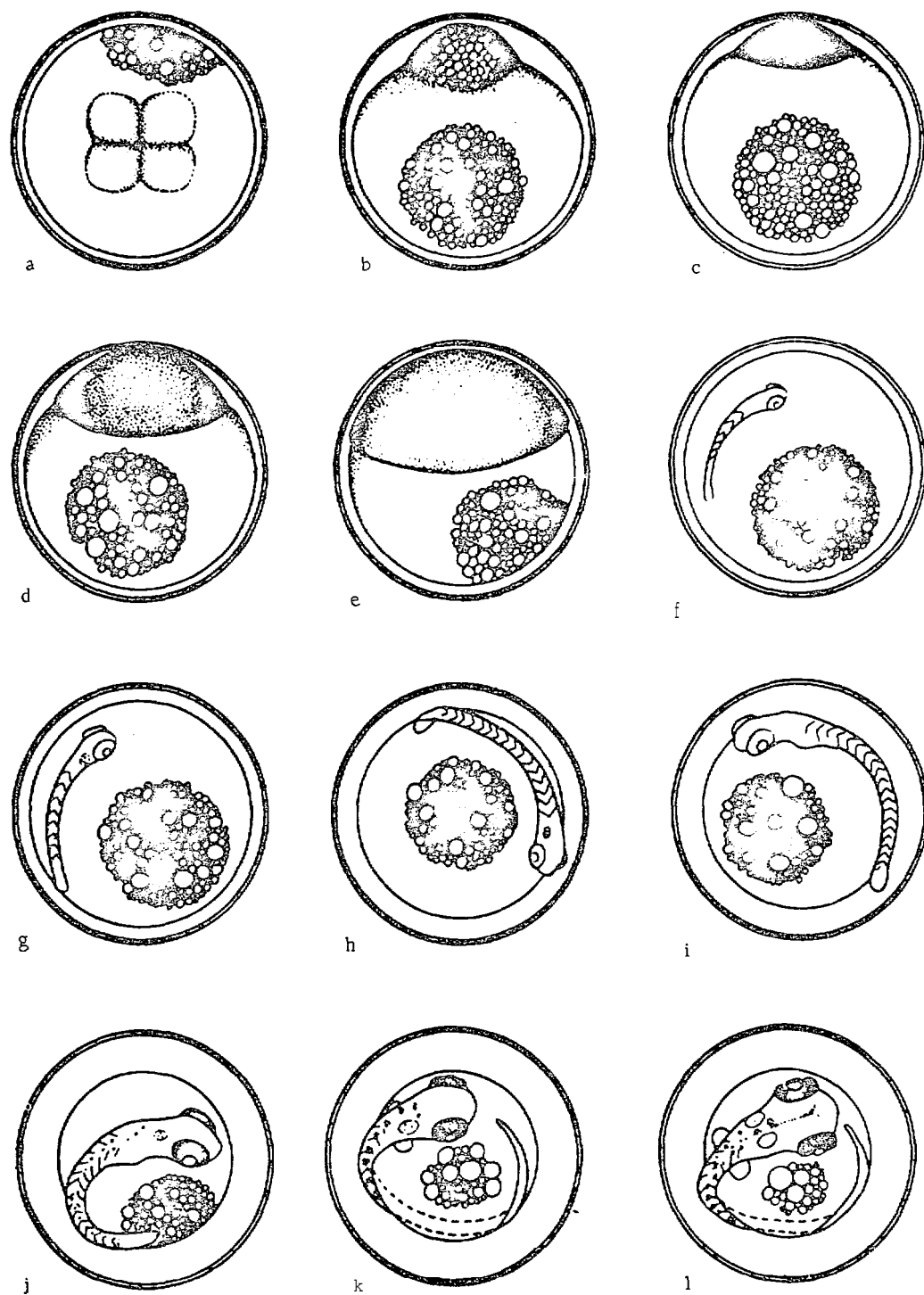
Figure III.24.7---Embryonic development of_Pleurogrammus_monopterygius:
a - 7 hours; b - 1 day (24 hr); c - 2 days; d - 3 days; e - 5 days;
f - 7 days; g - 8 days; h - 9 days; i - 10 days; j - 14 days;
k - 17 days; 1 - 19 days (from Gorbunova 1962).
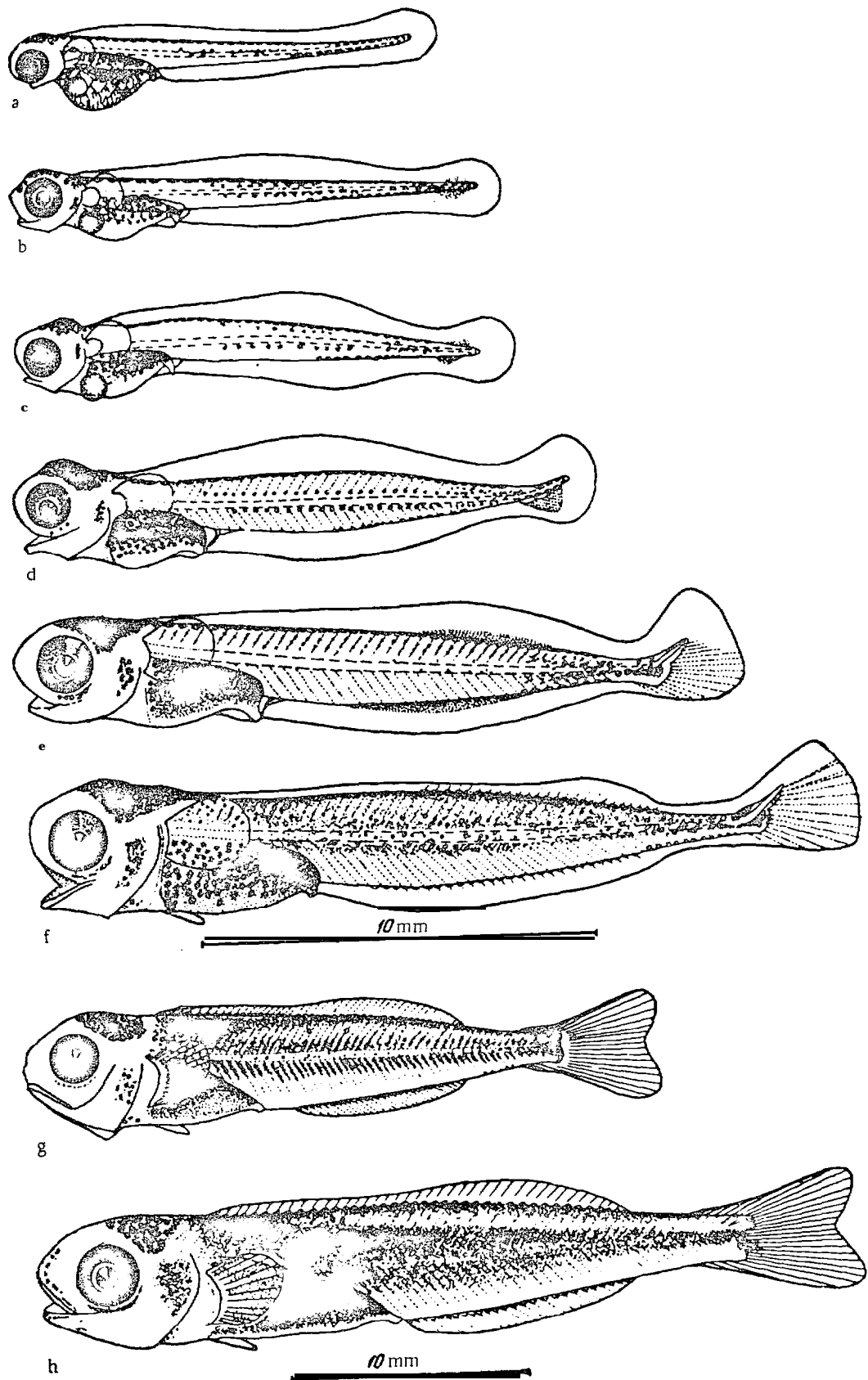
Figure III.24.8.--Larvae and fingerlings of Pleurogrammus monopterygius:
a - 10.5 mm; b - 11.8 mm; c - 12.0 mm; d - 14.1 mm; e - 17.3 mm;
f - 19.4 mm; g - 23.1 mm; h- 30,0 mm (from Gorbunova 1962).

Table 111.24.2 .--Monthly size composition of larvae and
fingerlings of Pleurogrammus monopterygius off the
east coast of Kamchatka (from Gorbunova 1962).

Month and Length (in mm)						
Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Source
10.0-10.5	6.8-12.5	7.5-14.3	12,.0-23.0	9.3-24.0	--	Gorbunova (1962)
--					--	Kobayashi's data (1957-1960)
March	April	May	June	July	Aug.	
13,0-26.5	15.5-30.0	37.1	--	--	--	Gorbunova (1962)
--	--	20.0-46.5	14.0-62.4	25,5-73.1	170.0-190.0	Kobayashi's data (1957-

Table 111.24.3. --Relationship between length and age in
Pleurogrammus monopterygius taken off the eastern
coast of Kamchatka (from Gorbunova 1962).

Sex	Age (years-) and Length (cm)				
	3	4	5	6	7
Females	33.0	35.0	38.8	43.2	44.0
	(32.0-34.0)	(31.0-35.5)	(39.0-41.0)	(33.0-44.0)	(41.0-47.0)
	8	9	10	11	
	48.0	51.1	53.2	56.5	
	(45.0-53.0)	(50.0-53.0)	(52.0-54.5)		
Males	3	4	5	6	7
	--	33.5	36.5	39.1	40.6
		(31.0-35.5)	(35.0-40.0)	(37.0-40.0)	(38.0-44.0)
	8	9	10	11	
	42.5	--	50.0	--	
	(42,0-43.0)				

Information on the diet of Pleurogrammus seems to be rather limited. Gorbunova
(1962) indicated that larval fish feed on plankton in the open sea. Meek
(1916) felt that even the adult fish are largely plankton feeders, consuming
primarily copepods and other microcrustaceans. Andriyashev (1954) reported
that no feeding studies of Atka mackerel had yet been conducted in the
Bering Sea, but that remnants of euphausiids were found in the stomach
contents of specimens collected off the Commander Islands at a depth of
107 to 124 meters. Rutenberg (1962) stated, however, that Atka mackerel
feed on small fish, crustaceans, mollusks, worms, and hydroids while in
inshore waters and change to plankton during their pelagic period.
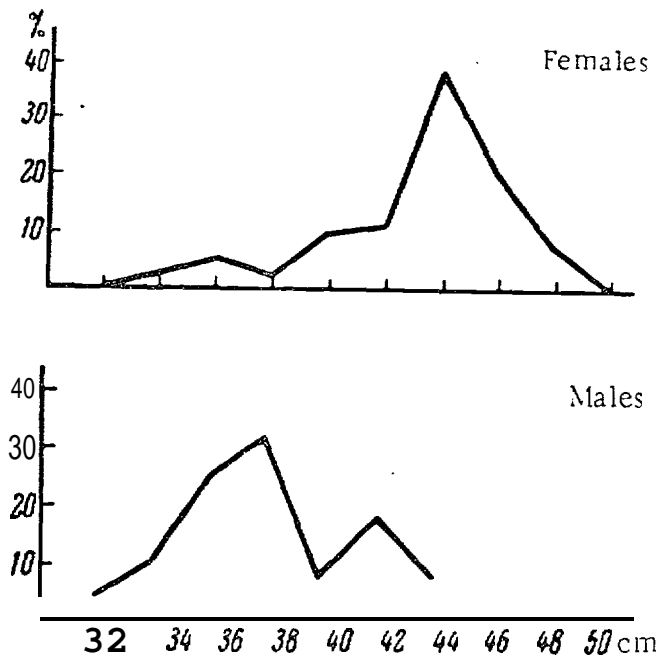
Figure 111.24.9.--Size composition of a school of Atka mackerel
spawning near Kamchatka (according to catches with fixed
gillnets). (From Gorbunova 1962.)

Predators

Atka mackerel is fairly important in the diet of a number of fish, birds,
and mammals at various stages of its life cycle. The greenling, Hexagrammos
lagocephalus, and the Irish lord, Hemilepidotus jordani, which inhabit
the spawning grounds of the Atka mackerel , consume quantities of the newly
deposited eggs before they have solidified (Gorbunova 1962). Pleurogrammus
larvae of 25-30 mm length are frequently found in the stomach contents
of salmon caught in the open ocean. During the annual migrations to the
spawning grounds, both the young and the adult fish fall prey to cods,
large halibut, fur seals, and sea lions (Andriyashev 1954). Various authors
emphasize the importance of Atka mackerel in the diet of cod. Andriyashev
(1937) reported that as many as five are sometimes found in the stomach
of a large cod. Tarleton Bean (1887) mentions the excellence of this greenling
as bait, writing "Cod are passionately fond of this fish. .." Apparently,
both cod (Wilcox 1895) and halibut (Rutenberg 1962) follow the schools
to their spawning grounds , and halibut at least (Turner 1886, Rutenberg
1962) continue feeding on them while the spawning is taking place. The
finding of a specimen in the nest of a bald eagle (Scheffer 1959) indicates
that it may be a feature in the diet of such raptors.

Fur seals and sea lions have long been known to prey upon these greenings.
Turner (1886) even felt that the local distribution of the Atka mackerel
may be affected by the presence of the Steller's sea lion. Statistics
from the North Pacific Fur Seal Commission (1962, 1969, 1971, 1975) indicate
that the proportion of Pleurogrammus monopterygius in the diet of fur
seals seems to vary considerably with the location, time of year, and
the year. In the southwest Bering Sea, off the Commander Islands, Atka
mackerel and other greenings constituted an average of 82% by weight

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of the stomach contents of male fur seals in **1967, 1968,** and 1970 (North Pacific Fur Seal Commission 1975). While Atka mackerel seem to be somewhat less important in the diet of fur seals in the eastern Bering Sea and Gulf of Alaska, they did contribute anywhere from 0.1% of the stomach contents by volume in the Bering Sea and Unimak Pass (March to April 1960) to 49.9% off western Alaska in the summer of 1968 (Marine Mammal Biological Laboratory 1970) (Fig. 111.24.10). In 1962, Atka mackerel was found in the stomach contents of fur seals caught from June to October (Fig. 111.24.5), ranking second in importance in the Bering Sea (Fiscus, Baines, and Wilke 1964). The food of sperm whales (Physeter catodon) in the Bering Sea and Kurile Islands included the Atka mackerel according to Sleptsov (1952).

Parasites

Although Rutenberg (1962) feels that parasites are one of the three most important biological determinants of distribution of the Hexagrammidae, very little mention is made in the literature. Parasitic copepods have been found on Atka mackerel off the Commander Islands; Rutenberg (1962) cited Wilson (1905) as reporting a new species of Caligidae (Lepeophtheirus paraviventris) and Gusev (1951) as finding Clavella uncinata.

Behavior

The schooling behavior of prespawning and spawning mackerel was recognized by Tarleton Bean (1887) , and Alexander Meek (1916) noted that the immature fish also migrate in shoals to the spawning grounds. Little mention is made, however, as to whether the Atka mackerel school during the remainder of the year.

Because the spawning migrations of the Atka mackerel are a fairly prominent feature of the Aleutians at certain times of the year, the inshore movements of these fish have long been known. Turner (1886) noted that the Atka mackerel come from the Pacific side of the Aleutians and arrive in the pass between Atka and Amlia around the first of June. Tanner (1890) reported that schools of Pleurogrammus approach the Shumagin Islands in late August and make the opposite migration to deeper water at the commencement of cold weather. Similar migrations occur at Chichagof Bay on Attu Island (Rutenberg 1962) and at Cape Nalychev in the U.S.S.R. (Medveditsyna 1962) and may be supposed to occur enroute to and from all spawning areas. Apparently Atka mackerel may sometimes avoid a usual spawning area in certain years, as Bean (1887) mentioned that the fish had reappeared at Iliuliuk, on Unalaska Island, after an absence of a few years.

As has been previously mentioned, a number of predatory species, such as cod, halibut, fur seals, and sea lions are frequently found in close association with schools of Atka mackerel (Andriyashev 1954). Symbiotic associations with this species are unknown.
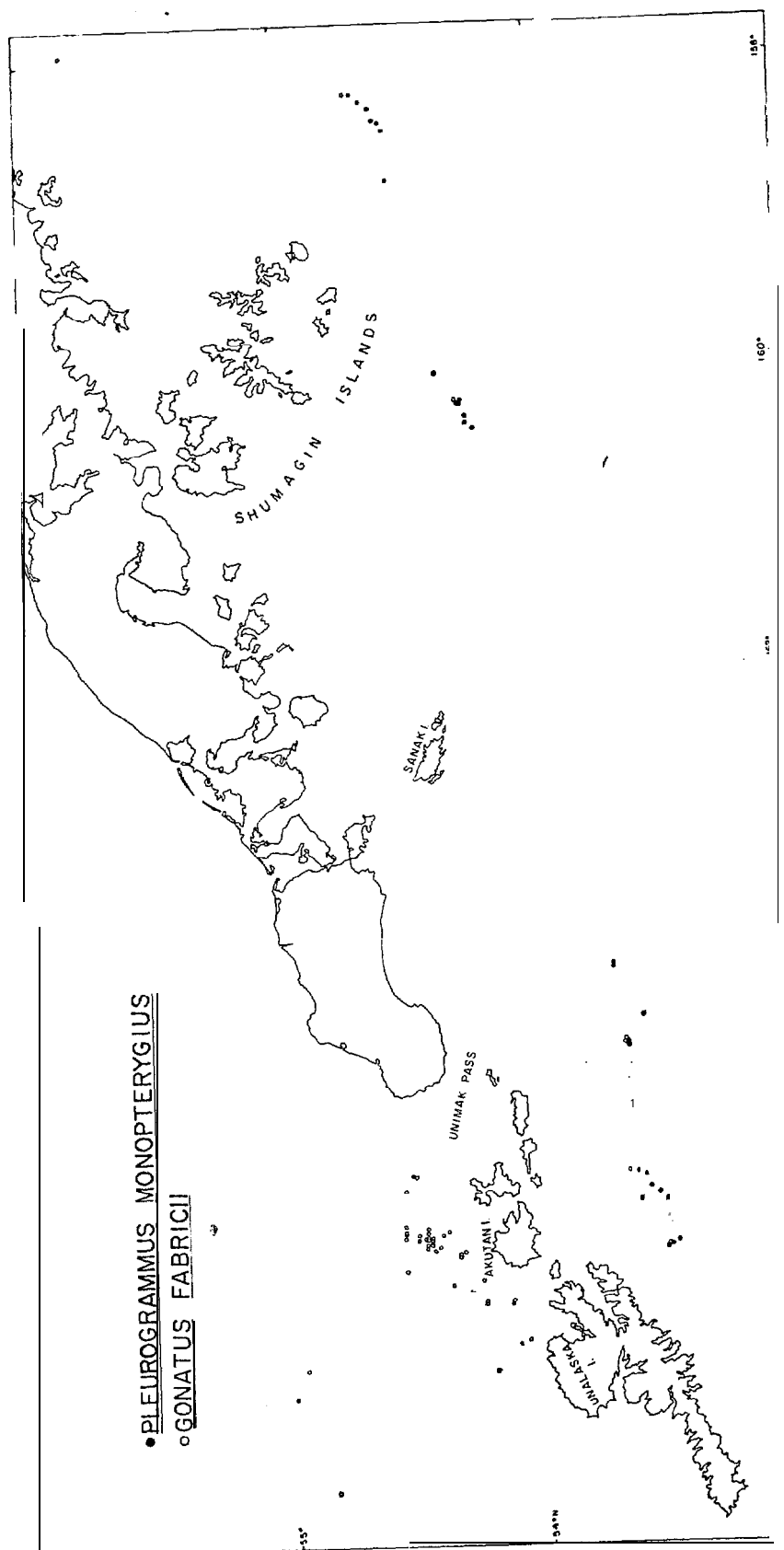
Figure III.24.10.—Locations where fur seal stomachs collected off western Alaska and in the Bering Sea contained Pleurogrammus monopterygius (34 occurrences) and Gonatus fabricii (37 occurrences). (From Marine Mammal Biological Laboratory 1970).

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POPULATION STRUCTURE AND DYNAMICS

Very little information can be found in the literature concerning the population composition and dynamics of Pleurogrammus monopterygius. Early reports by Turner (1886) and Tanner (1890) indicate that the fish were very abundant around the Aleutian and Shumagin Islands in the late 1800's. During recent years, Soviet vessels have been taking large quantities of Atka mackerel in the Gulf of Alaska and near the Aleutians, indicating that commercial quantities do exist in those areas (National Marine Fisheries Service 1973-75b; U.S.S.R. unpublished catch statistics).

FISHING

History of the Fishery

The native fisheries have long exploited the inshore concentrations of the spawning Atka mackerel. Turner (1886) described the method used by the natives on Atka to gig the fish on a long pole with a barbed hook. They anchored their canoe-like bidarka among the kelp where the fish were swarming, lowered the pole to the proper depth, then quickly jerked the pole up and down, spearing the fish on the hook. In this way they could catch 200 to 300 fish per hour. According to Tanner (1890), they used a similar method of fishing at Attu, but they attached three to four hooks together on a shift of polished lead or pewter. The fish apparently were attracted to the bright metal, then snagged on one of the hooks. Most of the fish were split and sun dried for consumption by the Aleuts, but in the late 1800's and early 1900's they found a market for a few barrels of salted fish annually by selling to ships on their way to St. Michael and Nome during the gold rush (Cobb 1906, 1907). Some barrels of the salted mackerel found their way to San Francisco where they were sold for as high as $28 per barrel (Bean 1887). Finding a ready market, some ships engaged in sealing and fishing began catching Atka mackerel. In the 1890's, the schooner Rosa Sparks returned to San Francisco with 324 barrels of the salted fish, which brought a price of $15 a barrel (Wilcox 1895). The Alaska Attu Mackerel Company was established at Seattle, Washington, in 1903 exclusively to fish for and cure this species. During that year they put up 400 half barrels on a trial basis, but no further activities of the company are known (Cobb 1906).

Little information is published on the present day commercial fishing of Atka mackerel. In the 1950's, Japan began large-scale fishing for Pleurogrammus (probably P. azonus) in Hokkaido waters and in 1952 brought in 140,000 metric tons of fish. According to unpublished U.S.S.R. catch statistics (Figs. 111.24.11, 111.24.12),-the first large catches of Atka mackerel in the Aleutians and western Gulf of Alaska were made in 1972, the fisheries yielding 4,515 and 6,282 metric tons, respectively. In the eastern Bering Sea , the catches have averaged less than 400 metric tons per year. More recently, Polish vessels fishing in the Kodiak Island area (lat 56-570N, long 152-153°W) caught a total of 620 tons in the winter of 1975, averaging as much as 46 metric tons per hour (Morski Instytut Rybacki w Gdyni 1976).

A few scattered reports (National Marine Fisheries Service 1973-75b) indicate that the U.S.S.R. at present has a fairly extensive fishery for Atka mackerel in the Gulf of Alaska and along the Aleutian chain. In April 1975, the Soviets had five trawlers, one research vessel, and one support
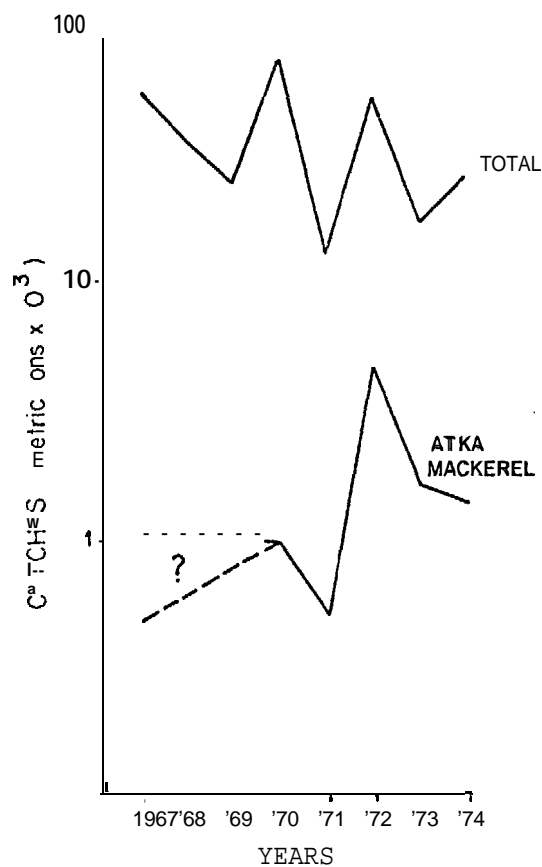
Figure 111.24.11 .--Catches of Atka mackerel
by the Soviet Union in the Aleutian
Island area (1967-74).
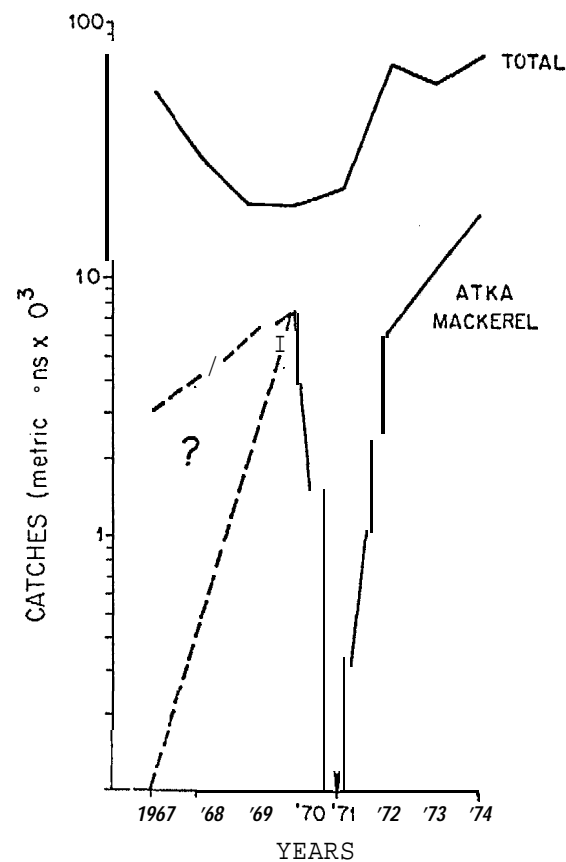
Figure 111.24.12. --Catches of Atka mackerel
by the Soviet Union in the western Gulf
of   Alaska   (1967-74).

Total Soviet catches of all fish species in the areas are shown on log scale for
comparison. In the years 1967 to 1970, the statistics on Atka mackerel were
grouped with those of various other species, but the figure for the actual catch
is presumed to be between the dotted lines (unpublished U.S.S.R. catch data).

vessel operating at Portlock Bank near Kodiak Island. By the end of August, a Soviet fleet centered at Petrel Bank (north of the Rat Islands group), and fishing primarily to Atka mackerel and rockfish, consisted of 35 stern trawlers, three refrigerated transports, one tanker, and a patrol vessel.

Gear Types and Uses

Various types of fishing gear are used to capture Atka mackerel, depending on the stage in the spawning period and on local conditions. In Kamchatka, during the May-June prespawning period, the Danish seine or trawl is used to catch fish at the 70 to 150 meter depths (Gorbunova 1962). An experimental research project in Avacha Bay, U.S.S.R. , indicated that purse seines were most effective when fished during the daytime hours and during June, July, and September, the height of the spawning season (Medveditsyna 1962). Fixed gill nets and pound nets are used to catch fish while they are in the shallow waters of the spawning area, but a rocky, uneven bottom may preclude the use of pound nets according to Gorbunova. In such cases, such as off the Kamchatka coast, set nets four to five meters high have been found more effective at catching both male and female fish. Local fishermen achieve good results at this time with hooks and handlines, the fish striking at a cod hook baited with fish or even with a small piece of red cloth (Rutenberg 1962, Medveditsyna 1962). Although Gorbunova felt that the trawl was unproductive during the middle of the spawning period, M.F. Vernidub (cited by Rutenberg 1962) found that over a ton of Atka mackerel could be caught with a trawl in the Olyutorskii Gulf in July. Medveditsyna (1962) recommended that trawls and fixed gill nets be used toward the end of the spawning season to catch the fish migrating out to sea. She also felt that trawls were most effective when used at night.

CONSERVATION AND MANAGEMENT REGULATIONS

Up to now, attention seems to have been focused on the most effective way to catch Atka mackerel and very little thought seems to have been given toward managing the resource. The only instance of management seems to have been an experiment to transplant Atka mackerel from east Kamchatka to the Barents Sea (Gorbunova 1962).

POTENTIAL CONTRIBUTION TO DOMESTIC AND INTERNATIONAL ECONOMY

As early as *1887*, Tarleton Bean felt that the Atka mackerel would some day become a very important part of the Alaskan fisheries. Numerous authors have remarked upon its tasty and nutritious flesh (Rutenberg 1962, Gorbunova 1962, Medveditsyna. 1962), and Tanner (1890) stated it is "... regarded by those who have eaten it as superior to any other on the coast of Alaska as an article of food." In addition to its potential importance as human food, it is also a valuable forage fish, forming a substantial part of the diet of cod, halibut, and other commercially valuable fish.

SUGGESTIONS FOR FUTURE RESEARCH

Because the Atka mackerel is being actively fish by Russians and Poles,
and perhaps other nations, in the Aleutian Islands area and the Gulf of
Alaska, more detailed data on the biology and distribution of this species
are needed. Future potential United States fisheries and fisheries management
requirements would necessitate a knowledge of the abundance and potential
sustained yield of the species. The Atka mackerel might possibly be a
valuable food fish for the United States market in the future.

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